

September 27, 2021

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RE: Demonstration of Preformed Chloramines for Biofouling Control and California Toxics Rule Compliance Study – Final Report (FSA Agreement 189515)

Dear Mr. Bentley:

San Diego County Water Authority submits the Final Report for the Demonstration of Preformed Chloramines for Biofouling Control and California Toxics Rule Compliance Study (Study) as documented in FSA Agreement 189515.

The attached Final Report submittal includes the discussion items required per the agreement along with the technical report provided by Padre Dam MWD's consultant Trussell Technologies Inc. as supporting documentation.

The total budget for the study is \$170,000 with \$80,000 funding match from the MWD. The study was completed with no revisions or impacts to the total study cost and MWD funding match. Total amount of funds submitted to date for the study is \$60,000 with \$20,000 remaining as retention.

I am informed and believe that the information contained in this report is true and that the supporting data is accurate and complete. Should you have any questions, please contact me at jcrutchfield@sdewa.org or (858) 522-6834.

Sincerely,



Jeremy Crutchfield
Water Resources Manager

Enclosure(s): Demonstration of Preformed Chloramines for Biofouling Control and California Toxics Rule Compliance – FINAL REPORT

**OTHER
REPRESENTATIVE**

County of San Diego

Final Report

Project Title:	Demonstration of Preformed Chloramines for Biofouling Control and California Toxics Rule Compliance
Grant:	Metropolitan Water District of Southern California's Future Supply Actions Funding Program
Recipient:	San Diego County Water Authority 4677 Overland Ave., San Diego, CA 92123
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Date Submitted:	September 27, 2021

Executive Summary

As a surface water augmentation project, the East County Advanced Water Purification (AWP) Project faces challenging requirements from the California Toxics Rule (CTR) for the disinfection byproducts N-nitrosodimethylamine, bromodichloromethane, and dibromochloromethane. This report summarizes the results from 12 months of testing to evaluate the use of preformed

chloramines as a means to achieve CTR compliance for these compounds. Implementation of preformed chloramines resulted in product water concentrations below the CTR limits for all three constituents. As a result, this study demonstrated that preformed chloramines could be a cost-effective solution to achieve CTR compliance for surface water augmentation projects and the East County AWP Project. Validating the success of the preformed chloramines alternative reduces cost-related barriers to implementation of surface water augmentation projects.

Introduction

Study Overview

Padre Dam Municipal Water District (Padre Dam) is leading the East County AWP Project which is a collaborative water supply project consisting of Padre Dam, Helix Water District, the County of San Diego, and the City of El Cajon. The Project will recycle tertiary treated wastewater through a newly constructed AWP Demonstration Facility to supplement the local drinking water reservoir, Lake Jennings. Lake Jennings is owned and operated by Helix Water District and provides raw water storage for operational flexibility to Helix's R. M. Levy Water Treatment Plant. The ECAWP Project will be one of the first surface water augmentation (SWA) projects in California that will be subject to the Division of Drinking Water's (DDW) SWA Regulations for the creating a new potable water source and the NPDES requirements for discharging purified water in Lake Jennings.

Lake Jennings is designated as an inland surface water in the San Diego Region Basin Plan which requires all discharges, including the purified water discharge from the AWP Demonstration Facility, to comply with the California Toxics Rule (CTR). The CTR establishes state-wide water quality standards for the protection of health of these aquatic ecosystems as well as the health of the humans that use these water bodies for drinking water or recreation. The challenge is that the CTR establishes very low limits for water quality constituents, with several constituents at or below the current detection limit. The two compounds of highest concern for achieving compliance with the CTR, due to their persistence through the RO treatment process, are the trihalomethanes (THMs) bromodichloromethane (BDCM) and dibromochloromethane (DBCM). BDCM and DBCM are disinfection byproducts which form in the presence of bromide, organic matter, and free chlorine.

This study was intended to demonstrate the feasibility of using preformed chloramines to eliminate or minimize the formation of THMs during advanced

water treatment to meet CTR limits for discharge of the purified water into Lake Jennings. Specifically, this study developed a test plan and design modifications to the existing 100,000 gpd AWP Demonstration Facility for the installation and operation of a preformed chloramines dosing system, monitored selected water quality constituents to assess the performance of the approach, and produced a report of the findings.

Trussell Technologies Inc., as the consultant to Padre Dam, conducted the study and produced the project report included in Attachment A.

Study Findings

The data collected at the AWP Demonstration Facility to evaluate the effectiveness of preformed chloramines indicated that preforming chloramines in reverse osmosis (RO) permeate before injecting into the AWP process feed helps maintain DBP levels below CTR thresholds.

Implementation of preformed chloramines does not require specialized training or equipment and it uses chemicals that will be already in place at the site. It also requires minimal additional equipment compared to the in-line chloramination option (static mixers, pump for carrier water).

The benefits of implementing preformed chloramination are significant as it offers the possibility of controlling formation of DBPs that are subject to regulatory compliance (DBCM, BDCM, NDMA).

This research project demonstrated that the preformed chloramines approach can be a simple, cost-effective solution to comply with CTR limits for THMs in the purified effluent, this allows the surface water augmentation projects to comply with the extremely low effluent limits set forth by the CTR.

This approach offers far less infrastructure and capital costs than the air stripping alternative: forming these compounds with the traditional chloramine pretreatment and subsequently stripping them out of the water.

Cost Summary

The study budget is presented in Table 1. Total budget for the study is \$170,000 with \$80,000 funding match from the MWD. The study was completed with no revisions or impacts to the total study cost and MWD funding match. However, a few adjustments were issued to revise the cost per task level slightly due to changes in the effort needed to complete each task during the actual

implementation of the study. Below is a summary of the adjustments made to the task level budgets with the executed amendments.

Adjustment No. 1

- Task 1 budget was revised from \$59,104 to \$75,421 with MWD funding match revised from \$27,927 to \$35,492. The implementation of the pH control in the preformed chloramines line required additional labor and supplies due to the challenges of measuring pH in low-ionic strength water (reverse osmosis permeate). Additional labor was required to troubleshoot and assist in the modifications of the demonstration plant.
- Task 2 budget was revised from \$83,992 to \$79,446 with MWD funding match revised from \$39,491 to \$37,396. Less budget needed due to lower cost of laboratory analyses.
- Task 3 budget was revised from \$26,904 to \$15,113 with MWD funding match revised from \$12,582 to \$7,112. Preparation of draft of preliminary findings of the study leveraged on task from separate contract and reduces the amount of labor needed to finalize report.

Adjustment No. 2

- Task 1 budget was revised from \$75,421 to \$75,422 to account for rounding with the MWD funding match revised from \$35,492 to \$37,711 to align with the changes in task costs.
- Task 2 budget was revised from \$79,446 to \$79,465 to account for rounding with the MWD funding match revised from \$37,396 to \$35,117.
- No change to Task 3 budget or the MWD funding match.

Adjustment No. 3

- Task 1 MWD funding match revised from \$37,711 to \$37,702. This adjustment was made to include a deduction of \$8.50 from the Eligible Reimbursable Costs due to an exceedance of the maximum daily per diem by one of the subconsultants in Invoice No. 1.
- Task 2 MWD funding match revised from \$35,177 to \$35,186. This adjustment was made to include the balance \$8.50 deduction made to Task 1 MWD cost share.
- No change to Task 3 budget or the MWD funding match.

Table 1. Demonstration of Preformed Chloramination Study Budget¹

Task No.	Task Description	Total Study Cost	Metropolitan Funding Match
Task 1	Test Protocol and AWP Demonstration Facility Modifications	\$75,421	\$37,702
Task 2	CTR Monitoring	\$79,466	\$35,186
Task 3	Reporting	\$15,113	\$7,112
Totals		\$170,000	\$80,000

¹ - Reflects the Water Authority adjustments requested on June 9, 2021, and approved by Metropolitan . Values rounded to nearest dollar.

Table 2 identifies the cost incurred and funds disbursed throughout the duration of the Study between the two invoices processed. The only remaining item is the payment of the retention cost of \$20,000.

Table 2. Funds Disbursed throughout the Duration of the Study

Task No.	Task Description	Invoice #1 01/08/2019-03/31/2020		Invoice #2 04/01/2020-03/31/2021	
		Cost Incurred	Funds Disbursed	Cost Incurred	Funds Disbursed
Task 1	Test Protocol and AWP Demonstration Facility Modifications	\$75,421	\$37,702	\$0	\$0
Task 2	CTR Monitoring	\$40,057	\$20,028	\$39,409	\$15,158
Task 3	Reporting and Final Presentation	\$0	\$0	\$15,113	\$7,112
	Retention		(\$14,432)		(\$5,568)
Totals		\$115,478	\$43,298	\$54,522	\$16,702

Values rounded to nearest dollar.

Schedule Summary

Table 3 shows the study schedule indicating actual progress from the planning schedule in the agreement. The actual implementation schedule for the study was in line with the planned schedule. The only remaining project milestone is the final presentation at the Fall Webinar which is scheduled for September 2021.

Table 3. Demonstration of Preformed Chloramination Study Schedule

Task No.	Task Description	Start	End	Status
Task 1	Test Protocol and AWP Demonstration Facility Modifications	April 2019	June 2019	Completed
Task 2	CTR Monitoring	July 2019	December 2020	Completed
Task 3	Reporting			
	Draft Report	October 2020	May 2021	Completed January 2021
	Final Report		July 2021	Completed June 2021

Study Results and Analysis

The Study Technical Report provided as Attachment A describes the project goals, testing methods, water quality monitoring conducted, and the study results in details.

In summary, the data collected at the AWP Demonstration Facility to evaluate the effectiveness of preformed chloramines indicate that preforming chloramines in RO permeate before injecting into the AWP feed helps maintain DBP levels below CTR thresholds. Particularly, BDCM and DBCM were consistently below the method reporting limit (0.50 µg/L) and detection limit (0.12 µg/L for BDCM and 0.062 µg/L for DBCM) in the UV/AOP effluent during the study. NDMA is removed during RO and UV/AOP, consistently below detection (<0.96 ng/L) in the UV/AOP effluent, and there was no evidence of reformation after UV treatment. Although no major problems occurred in meeting the Study goals and objectives, the COVID-pandemic did cause a pause in the study due to limited operational staff presence onsite during stay-home order period. The benefits of implementing preformed chloramination are significant as it offers the possibility of controlling formation of DBPs that are subject to regulatory compliance (DBCM, BDCM, NDMA) or that may pose operational challenges (bromamines).

This research project demonstrated that the preformed chloramines approach can be a simple, cost-effective solution to comply with CTR limits for THMs in the purified effluent. Mixing preformed chloramines in the AWP influent is a method which retains biofouling control while preventing the formation of THMs by preforming the chloramines in a clean RO permeate sidestream (low in disinfection byproduct precursors). Therefore, by preventing the formation of

THMs, this allows surface water augmentation projects to comply with the extremely low effluent limits set forth by the CTR. This approach offers far less infrastructure and capital costs than the air stripping alternative: forming these compounds with the traditional chloramine pretreatment and subsequently stripping them out of the water.

This study proved successful implementation of the preformed chloramines approach to make surface water augmentation more attainable in California by reducing the costs associated with CTR compliance. Through the validation of this cost-effective solution to comply with strict effluent CTR limitations in receiving reservoirs, this research will reduce barriers to the implementation of surface water augmentation in California.

The East County AWP Project decided to include preformed chloramination in the full-scale facility design. No obstacles are anticipated before implementation/application can occur.

Conclusion

Following the successful completion of the pilot testing of the preformed chloramination approach for the membrane protection and CTR compliance, the technical team working on the East County AWP Project decided to include preformed chloramination in the full-scale facility design. A few lessons learned from the pilot testing included confirmation of (1) the chemistry working as planned in the field and (2) importance of the order of chemical injection and mixing in achieving successful results.

The next steps include completion of the design drawings by end of 2021. Construction of the full-scale facility is scheduled to be completed by end of 2024 with startup and commissioning activities completed by March 2025.

Attachments

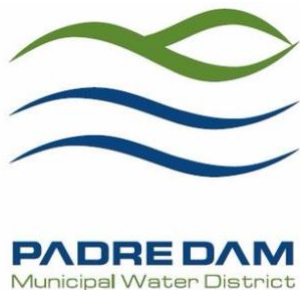
Attachment A - Final Report: Preformed Chloramines Study for California Toxics Rule Compliance, Trussell Technologies Inc., March 2021

Final Report - Preformed Chloramines Study for California Toxics Rule Compliance

March 2021



Prepared for:



Prepared by:





Preformed Chloramines for CTR Compliance

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Acronyms and Abbreviations

AWP	Advanced Water Purification
BDCM	Bromodichloromethane
CT	Concentration x contact time
CTR	California Toxics Rule
DBCM	Dibromochloromethane
DBP	Disinfection byproducts
DEHP	di(2-ethylhexyl)phthalate
gpd	Gallons per day
gpm	Gallons per minute
MCL	Maximum contaminant level
MDL	Method detection limit
MF	Membrane Filtration
MGD	Million gallons per day
MRL	Method reporting limit
N-OM	Nitrogenous organic matter
NDMA	N-nitrosodimethylamine
ng/L	Nanograms per liter
NPDES	National Pollutant Discharge Elimination System
Padre Dam	Padre Dam Municipal Water District
RO	Reverse Osmosis
RSD	Relative standard deviations
RWQCB	Regional Water Quality Control Board
SWA	Surface Water Augmentation
TDS	Total dissolved solids
THM	Trihalomethane
TOC	Total organic carbon
tTHM	Total trihalomethanes
µg/L	Micrograms per liter
USEPA	United States Environmental Protection Agency
UV/AOP	Ultraviolet advanced oxidation process
WRF	Water Recycling Facility
WTP	Water treatment plant

Chemical Formulas

HOBr	Hypobromous acid
HOCl	Hypochlorous acid
NCl ₃	Trichloramine
NH ₂ Cl	Monochloramine
NH ₃	Ammonia
NHCl ₂	Dichloramine



1 Executive Summary

As a surface water augmentation project, the East County Advanced Water Purification (AWP) Project faces challenging requirements from the California Toxics Rule (CTR) for the disinfection byproducts N-nitrosodimethylamine, bromodichloromethane, and dibromochloromethane. This report summarizes the results from 12 months of testing to evaluate the use of preformed chloramines as a means to achieve CTR compliance for these compounds. Implementation of preformed chloramines resulted in product water concentrations below the CTR limits for all three constituents. As a result, this study demonstrated that preformed chloramines could be a cost-effective solution to achieve CTR compliance for surface water augmentation projects and the East County AWP Project. Validating the success of the preformed chloramines alternative reduces cost-related barriers to implementation of surface water augmentation projects.

2 Introduction

2.1 Project Background and Regulatory Requirements

The East County Advanced Water Purification Project (East County AWP Project or Project) was developed in partnership with Padre Dam Municipal Water District (Padre Dam), Helix Water District, the County of San Diego, and the City of El Cajon to provide East San Diego County with a new source of local, reliable, drought-proof water for potable use. Together, these four agencies are pursuing a surface water augmentation (SWA) potable reuse project. Advanced treated water (purified water) will be produced at the Advanced Water Purification Facility via full advanced treatment of tertiary effluent with membrane filtration (MF), reverse osmosis (RO), and ultraviolet advanced oxidation process (UV/AOP) with free chlorine. After treatment, 11.5 million gallons per day (MGD) of purified water will be conveyed to Lake Jennings via a pipeline in which free chlorine disinfection will take place. Lake Jennings is a local reservoir, which serves as a water source for the R.M. Levy Water Treatment Plant (R.M. Levy WTP), both of which are owned by Helix Water District. The drinking water from the WTP will then be distributed to Helix Water District's service area, which also includes Padre Dam, Otay, and Lakeside Water Districts.

Padre Dam has been operating a 100,000-gallons per day (gpd) capacity AWP Demonstration Facility since 2015 to test various treatment technologies, promote public outreach, support full-scale design, and help secure regulatory approval of the East County AWP Project. This research project installed a preformed chloramines system at the AWP Demonstration Facility to pilot test the system for one year to ensure California Toxics Rule (CTR) compliance and provide valuable information on validation of the method for full-scale design and implementation.

The CTR establishes state-wide water quality standards for inland surface waters, enclosed bays, and estuaries to protect aquatic ecosystems and human health. The rule was promulgated in 2000 by the United States Environmental Protection Agency (USEPA) as "Water Quality Standards; Establishment of Numeric Criteria for Priority Pollutants for the State of California" and updated in 2001. Discharge of purified water to Lake Jennings for SWA is subject to the specific water quality standards listed in the CTR, which must be met at the end of the discharge pipe, unless a mixing zone is authorized by the Regional Water Quality Control Board (RWQCB). The two compounds of highest concern for achieving compliance with the CTR, due to their persistence through the RO treatment process, are the trihalomethanes



Preformed Chloramines for CTR Compliance

(THMs), bromodichloromethane (BDCM), and dibromochloromethane (DBCM). These are disinfection byproducts (DBPs) formed through reactions with free chlorine during water treatment. Another compound of concern for CTR compliance is N-nitrosodimethylamine (NDMA), a probable human carcinogen, which can be formed during chloramination.

2.2 East County AWP Project Water Quality and CTR Constituents

A study conducted in 2015–2016 at Padre Dam’s 100,000-gpd capacity AWP Demonstration Facility monitored the concentration of BDCM and DBCM through the advanced treatment and in the product water. The advanced treatment train at the AWP Demonstration Facility consisted of free chlorine disinfection of the AWP feed with a design residual concentration x time (CT) value of 10 mg/L-min, followed by MF, RO, and UV/AOP with free chlorine as the oxidant. The AWP feed was nitrified/denitrified secondary effluent from the existing Ray Stoyer Water Recycling Facility (WRF).

The average concentration of BDCM and DBCM measured along the advanced treatment train is presented in **Figure 1**. BDCM and DBCM were not detected (<0.50 µg/L) in the secondary effluent. The secondary effluent contains sufficient inorganic and organic precursors to form THMs when subject to free chlorine disinfection as evidenced by the increase in the concentration of BDCM and DBCM in the effluent of the chlorine contactor (Free Chlorine Effluent in **Figure 1**). Partial removal was observed through RO and UV/AOP, however UV/AOP effluent concentrations of BDCM and DBCM were still consistently in exceedance of the CTR limits for discharge to Lake Jennings. BDCM was observed at much higher concentrations than DBCM relative to its CTR limit.

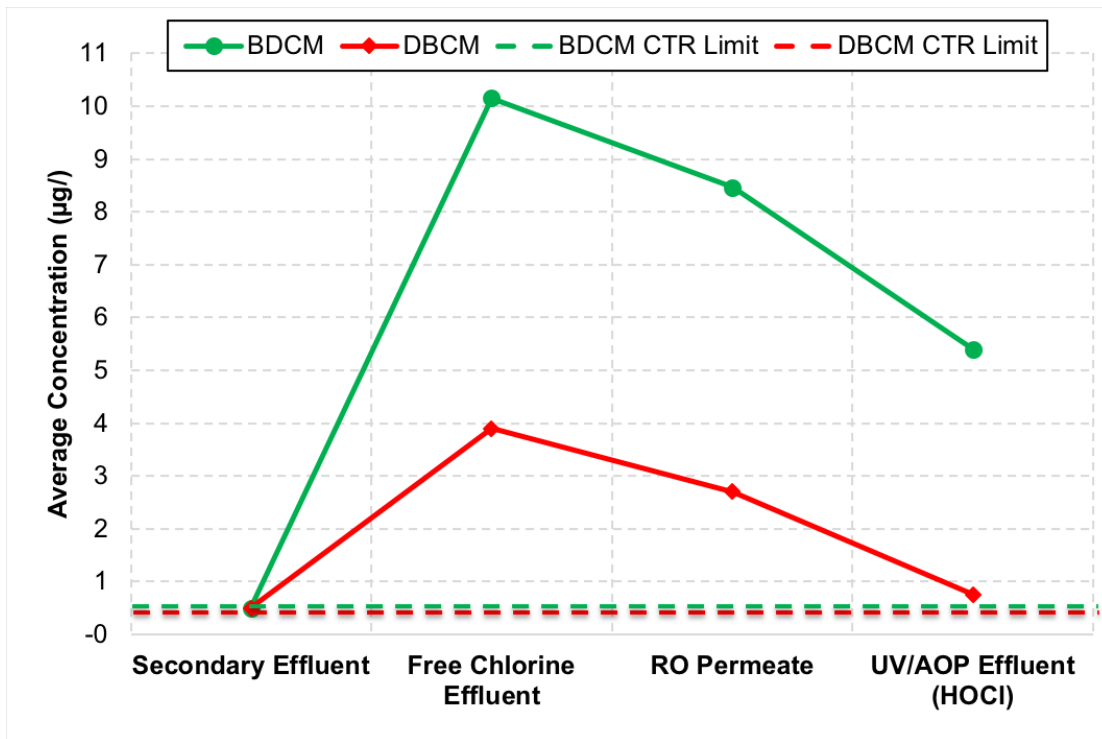


Figure 1: Average concentration of DBCM and BDCM in the AWP Demonstration Facility during the 2015-2016 Demonstration Study.



The average and maximum AWP Demonstration Facility effluent BDCM and DBCM concentrations measured between May 2015 and February 2016 are presented in **Table 1**. Ten different sampling conditions were tested during this time period with free chlorine used as the oxidant in the UV/AOP. Both the average and maximum concentrations of BDCM and DBCM in the UV/AOP effluent were observed to exceed the CTR limits required for discharge into Lake Jennings. Therefore, compliance strategies for BDCM and DBCM are needed in the full-scale treatment in order to meet expected effluent limitations in the National Pollutant Discharge Elimination System (NPDES) permit.

Table 1: Concentrations of BDCM and DBCM Measured in the Effluent of the AWP Demonstration Facility in 2015-2016

THM	CTR Limit	Average ^(a)	Maximum ^(b)	Required Removal for CTR Compliance ^(c)
BDCM	0.56 µg/L	5.4 µg/L	6.8 µg/L	92%
DBCM	0.41 µg/L	0.76 µg/L	1.1 µg/L	63%

- (a) Average of 10 sampling conditions (between 05/15 and 02/16) with free chlorine as the oxidant (doses of 1-4 mg/L Cl₂ in UV/AOP).
- (b) Maximum of 10 sampling conditions (between 05/15 and 02/16) with free chlorine as the oxidant (doses of 1-4 mg/L Cl₂ in UV/AOP).
- (c) Percent removal assuming the maximum observed concentrations.

Compliance strategies can be aimed at removing the DBPs formed during treatment (e.g., air stripping) or at minimizing or preventing their formation by removing precursors (e.g., ozone with biologically active filtration) or preventing the reactions with precursors from occurring (use of preformed chloramines). The most efficient downstream removal process would be the installation of air stripping towers, which leverage the volatility of these compounds to strip them from the purified water. The stripping tower alternative, however, represents far higher costs (capital and operations and maintenance) due to significant infrastructure, footprint, and pumping. Another method to comply with the BDCM and DBCM limits established by CTR involves removing the precursors (i.e., organic matter) prior to chloramination through ozone with biologically active filtration. These are two additional treatment processes with significant associated costs.

The preformed chloramines alternative requires modest piping changes and uses the same chemicals as conventional chloramination. The installation and operation of a preformed chloramines system does not require a significant increase in costs over a conventional chloramine pretreatment system.

Previously, the Project conducted a desktop evaluation of air stripping and preformed chloramines as strategies to achieve CTR compliance (Padre Dam Municipal Water District, 2018). The study concluded that using preformed chloramines represented a cost-effective and proactive strategy to control DBP formation compared to air stripping.

2.3 Implementation of Preformed Chloramines in Full- and Pilot-Scale Projects

Chloramination is an important pretreatment step in membrane treatment to control biofouling in order to maintain design fluxes in the MF and RO processes and ultimately produce the targeted amount of purified effluent. Historically, conventional chloramination by dosing ammonia and free chlorine into the process flow has been adequate for groundwater recharge



projects which do not need to comply with the strict discharge requirements included in the CTR. Preformed chloramines to control biofouling for membranes is a proven technology but is not common in the US and/or for potable reuse. The principle of the preformed chloramines approach is to form the chloramines in a sidestream with water that is low in DBP precursors and then inject this solution into the main line upstream of the membranes. This prevents the contact of free chlorine with water constituents and, as such, minimizes the formation of products from chlorine oxidation.

The use of preformed chloramination in advanced treatment was investigated in local pilot tests including the West Basin Municipal Water District Temporary Ocean Water Desalination Demonstration Project and the Donald C. Tillman Ground Water Replenishment Advanced Water Purification Facility Pilot Project for the City of Los Angeles (Trussell Technologies, 2008; Brown and Caldwell and Trussell Technologies, 2017). The West Basin project aimed to reduce the formation of bromamines while the D.C. Tillman project sought to reduce NDMA formation. The Pure Water San Diego – Phase 1 Project will be performing pilot-scale testing of preformed chloramines as part of a study to investigate the various factors affecting bromamine and hypobromous acid formation and develop strategies to minimize formation of undesirable DBPs and extend RO membrane longevity.

Currently, the Beenyup Advanced Water Recycling Plant in Perth, Australia uses preformed chloramines for biofouling prevention and DBP control and its product water complies with the Australian Drinking Water Guideline for NDMA (100 ng/L), BDCM (6 µg/L), and DBCM (100 µg/L) with all three compounds being below detection in the product water (<2 ng/L for NDMA and <1 µg/L for DBCM and BDCM)¹. The Beenyup Advanced Water Recycling Plant was created as part of the Water Corporation's groundwater replenishment scheme, which is aimed at providing a climate-independent water source to boost drinking water supplies in Perth. The treatment train has a 11-MGD capacity and consists of ultra-filtration, RO, and UV disinfection followed injection into groundwater for storage.

In Singapore, the advanced water treatment plants built as part of the NEWater Project (Singapore's potable reuse project to provide a sustainable water source to the country's drought-threatened supply) use preformed chloramines for biofouling prevention and to improve the treatment's operating performance and efficiency. This approach is used in all five of the Project's plants: Kranji (26 MGD), Bedok (22 MGD), Ulu Pandan (42 MGD), Changi 1&2 (120 MGD), which together supply up to 40% of Singapore's current water needs. The treatment train at the NEWater plants is composed of UF, RO, and UV, after which the water is sent to direct non-potable use or indirect potable reuse.

3 Preformed Chloramines as a Strategy for CTR Compliance

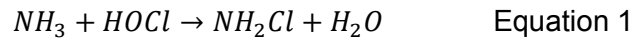
In the following sections, the use of preformed chloramines as a strategy to control formation of DBCM, BDCM, and NDMA are presented by demonstrating the involved chemical reactions during the treatment process.

¹ Personal communication with Dr. Stacey Hamilton from the Water Corporation of Western Australia in 2020.

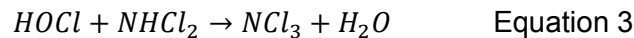
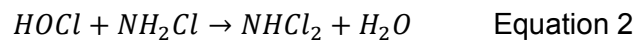


3.1 THM and NDMA Formation in Advanced Treatment

In advanced water treatment, chloramines are used to control biofouling in the membrane processes. Chloramines are effective disinfectants. They are more stable and less reactive than free chlorine, which allows them to prevent microbial growth without causing rapid damage to the membranes. In nitrified waters, monochloramine (NH_2Cl) is formed by the addition of free chlorine (HOCl) and ammonia (NH_3) to the feed water before MF treatment:



Additional chlorine will result in the formation of di- and tri-chloramine (NHCl_2 and NCl_3 , respectively):



The relative concentration of each chloramine species is governed mainly by pH and the ratio of chlorine to ammonia. In general terms, at a pH range of 7.5 to 9.0, monochloramine is the predominant species, while acidic pH (4 to 6) favors the formation of dichloramine. The optimal Cl:N mass ratio for the formation of monochloramine is from 3:1 to 5:1, while higher ratios (5:1 to 7.6:1) favor dichloramine.

During chloramination, reaction of free chlorine with naturally occurring bromide and organic matter (i.e., inorganic and organic precursors) can result in the formation of BDCM and DBCM (**Figure 2**). Once formed, these THMs are reduced but not entirely removed by advanced treatment. In drinking water, THMs are regulated under the Disinfection Byproducts Rules² by the sum of chloroform, BDCM, DBCM, and bromoform - known as total trihalomethanes (tTHM). The maximum contaminant level (MCL) for tTHM is 80 microgram per liter ($\mu\text{g/L}$). Under the CTR, each of the four THMs is regulated individually; there is a unique numerical criterion for each compound. The CTR limits for BDCM and DBCM are particularly low, 0.56 $\mu\text{g/L}$ and 0.41 $\mu\text{g/L}$, respectively, based on a lifetime carcinogenicity risk of one in one million. The CTR limit for bromoform is 4.3 $\mu\text{g/L}$. In 1998, EPA decided to reserve a decision on numeric criteria for chloroform (denoted as "Reserved") and therefore did not promulgate chloroform criteria in the final rule.

² Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) 63 FR 69390, December 16, 1998, Vol. 63, No. 241

Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR) 71 FR 388, January 4, 2006, Vol. 71, No. 2

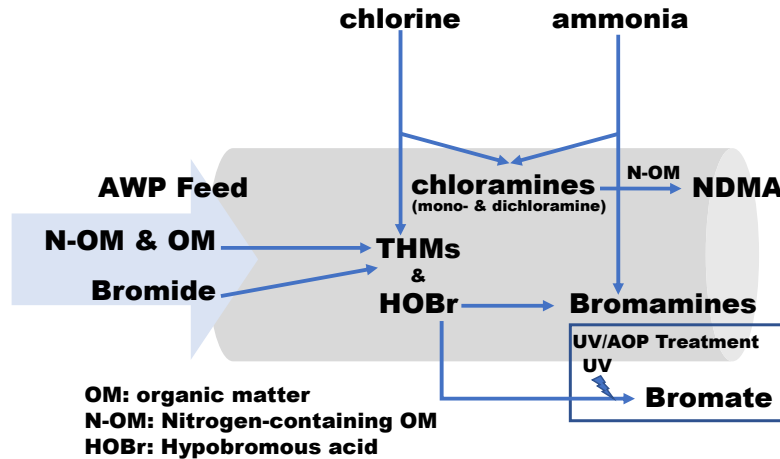


Figure 2: Schematic of the reactions that take place during the conventional process of chloramination of water containing organic and inorganic precursors of disinfection byproducts.

When free chlorine and ammonia are added to secondary or tertiary effluent to form chloramines, NDMA can be formed through the reaction of chloramine with nitrogen-containing organic matter (N-OM), such as dimethylamine, present in the water as shown in **Figure 2**. NDMA is a probable human carcinogen with a California Notification Level of 10 nanogram per liter (ng/L). It is also regulated under CTR with a limit of 0.69 ng/L. NDMA formation depends on the concentration of N-OM as well as on the speciation of the chloramines (Mitch et al, 2005). The rate of NDMA formation from the reaction of dichloramine with N-OM is much faster than that with monochloramine. During chloramination, addition of free chlorine prior to ammonia promotes the oxidation of N-OM, which reduces their reactivity with chloramines resulting in reduced NDMA formation (Schreiber and Mitch, 2005). Additionally, adding free chlorine first minimizes the formation of dichloramine by preventing localized regions of high Cl:N. Minimizing dichloramine formation also helps control NDMA formation since dichloramine reacts quickly to form NDMA.

Another water constituent that is important to consider in the context of chloramination and advanced water treatment is bromide. Bromide is a naturally occurring, non-toxic compound in water. During conventional chloramination, chlorine reacts rapidly with bromide, oxidizing it to form products that cause health effects or present operational challenges. In seawater or waters influenced by seawater intrusion, bromide levels can be high and lead to significant formation of bromide-containing DBPs during treatment. In addition to being one of the constituents involved in DBCM and BDCM formation, high levels of bromide can lead to the formation of bromamines and bromate. Bromamines are of concern because they are thought to cause significant oxidative damage to the membranes while bromate is a potential human carcinogen. During chloramination, bromide is oxidized by free chlorine to form hypobromous acid (HOBr), which reacts with ammonia to form bromamines. Additionally, the presence of HOBr can lead to the formation of bromate during UV treatment (Fang et al., 2017). The reactions leading to the formation of bromamines and bromate are illustrated in **Figure 2**.



3.2 Preformed Chloramines Strategy

The principle of the preformed chloramines approach is to form the chloramines in a sidestream with water that is low in DBP precursors and then inject this solution into the main line upstream of the membranes. This prevents the contact of free chlorine with water constituents and, as such, minimizes the formation of products from chlorine oxidation such as BDCM, DBCM, bromamines and HOBr. This is illustrated in the schematic in **Figure 3**. Additionally, the pH in the sidestream is increased to 8 through the addition of NaOH, which minimizes the formation of dichloramine. This is desired because dichloramine can react quickly with organic nitrogen compounds to form NDMA.

Once the preformed chloramine is injected into the feed water, reactions with the water constituents may still occur but to a much lower extent compared to the in-line chloramination alternative since free chlorine and DBP precursors will not be present. The carrier water used to preform the chloramines may be RO permeate, UV/AOP product water or tap water. Chloramines are preformed as a concentrated solution, so the amount of carrier water needed represents a small percentage of the total capacity of the treatment process (typically less than 1%).

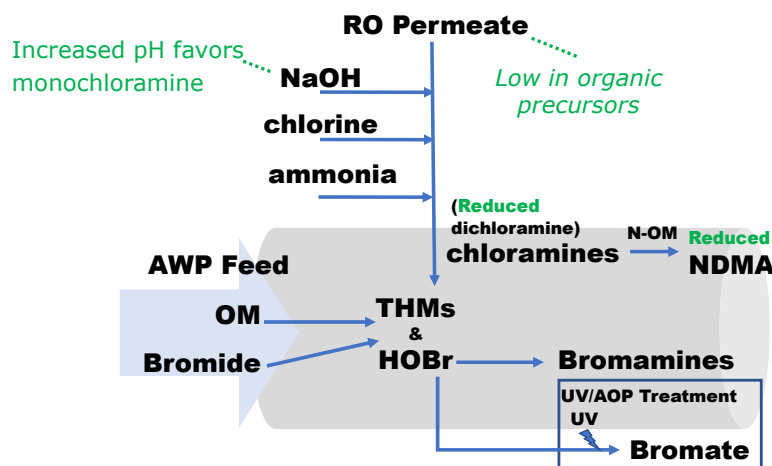


Figure 3: Schematic of the effect of using preformed chloramines in the formation of DBPs.

At a simplified level, the extent of THM formation is related to the amount of time available for free chlorine to react with organic precursors in the water. Data from chlorination bench-testing of secondary effluent from Ray Stoyer WRF are presented in **Figure 4**. There is a positive correlation between THM formation and free chlorine CT. Combined chlorine in the form of chloramines is much less reactive with these organic precursors as no additional THMs are formed with the subsequent chloramine contact time. Based on these observations of slow reaction kinetics for combined chlorine and taking into consideration the short contact periods that will occur during advanced treatment, the use of preformed chloramines would virtually avoid formation of detectable concentrations of BDCM and DBCM altogether.

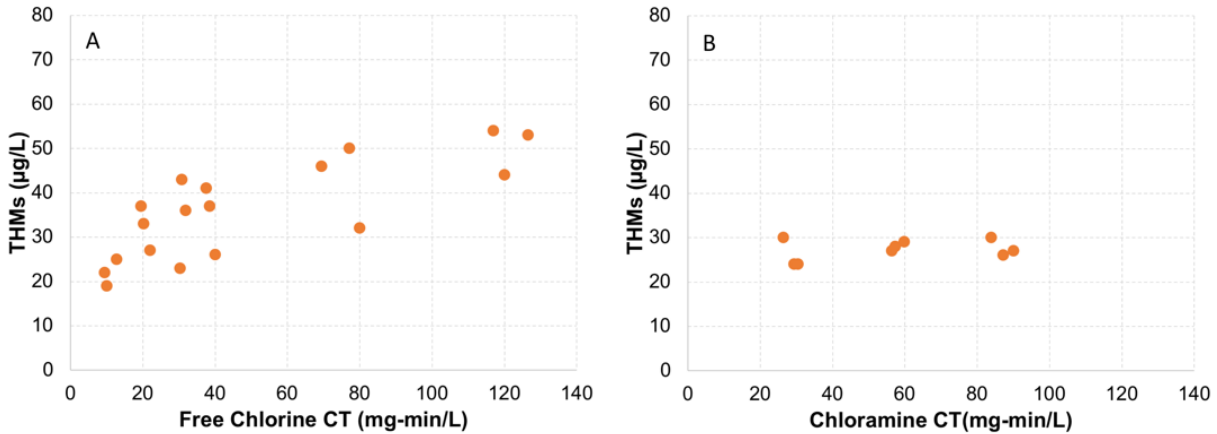


Figure 4: A: THM formation as a function of free chlorine CT. B: THM formation as a function of chloramine CT after free chlorine CT of 10 mg-min/L.

During conventional chloramination, most of the free chlorine added reacts rapidly with ammonia to form chloramines but some of the free chlorine also reacts with bromide to form hypobromous acid. One strategy for avoiding HOBr formation is to combine free chlorine and ammonia first to “preform” the chloramines and then add the preformed chloramines to the process. Unlike free chlorine, chloramines react very slowly with bromide. As a result, this process reduces the formation of HOBr and, consequently, brominated DBPs.

Removing all free chlorine contact in the AWP feed water provides a more proactive strategy for controlling BDCM and DBCM as opposed to treatments focused on removing these constituents after they are formed. The use of preformed chloramines has also been shown to result in lower concentrations of halogenated DBPs compared to free chlorine and in-line chloramination (Doederer et al., 2014).

4 Testing of Preformed Chloramines for the East County AWP Project

As described in the previous section, the use of preformed chloramines has been demonstrated in several projects. Its effectiveness for achieving CTR compliance for DBCM, BDCM, and NDMA for the East County AWP Project was evaluated at Padre Dam’s AWP Demonstration Facility. The sampling plan, analytical methods and procedures are summarized in this section. A detailed test plan for the preformed chloramines study was prepared in May 2019 and can be found in **Appendix 1**.

4.1 Preformed Chloramines System

A schematic of the preformed chloramines system used at Padre Dam’s AWP Demonstration Facility is presented in **Figure 5** and the actual system with its main components is shown in **Figure 6**. The preformed chloramines system consisted of a 1/2”-CPVC sidestream line with three injection ports in series for sodium hydroxide, sodium hypochlorite, and ammonium sulfate. RO Permeate was used as carrier water and its flow was set constant at 1 gallon per minute (gpm). The modifications performed in the AWP Demonstration Facility to install the preformed chloramines dosing system are indicated in the Test Plan included in **Appendix 1**. Instrument tags are indicated in parenthesis in Figure 5 next to the meter/analyzer description.

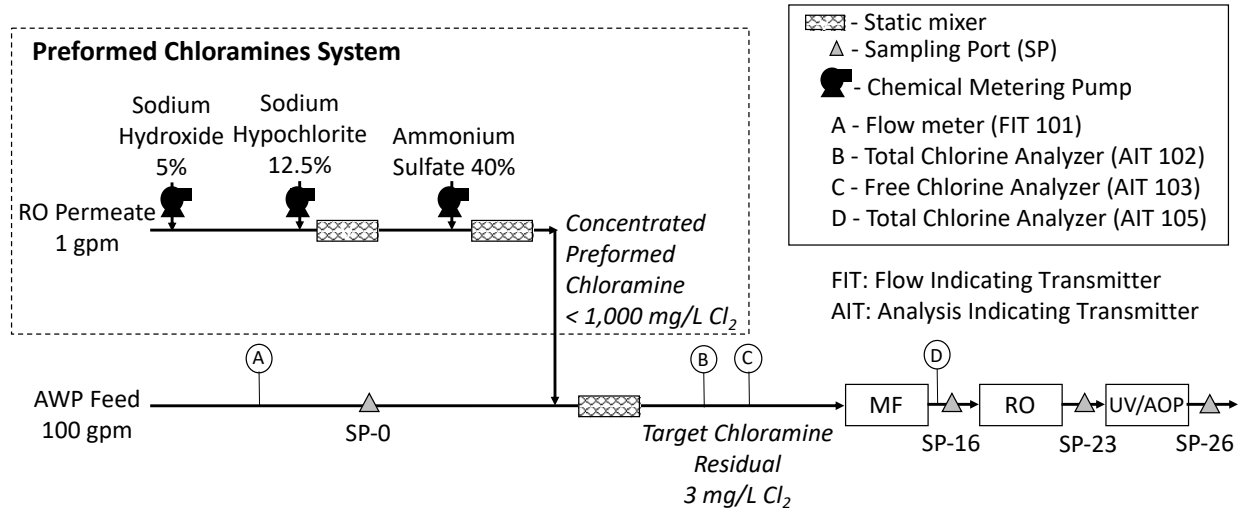


Figure 5: Schematic of the preformed chloramines system.

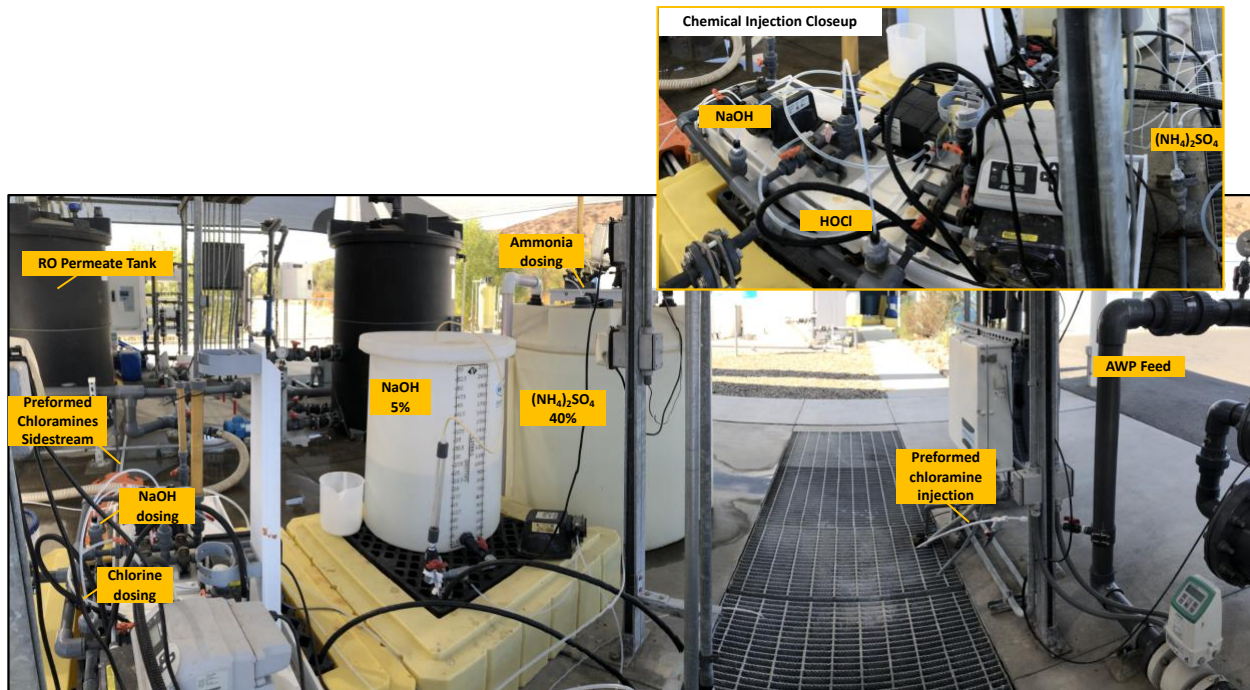


Figure 6: Photo of the preformed chloramines system at Padre Dam's AWP Demonstration Facility.

The following sequence of chemical addition was used:

1. **Caustic soda (sodium hydroxide):** a dilute solution of sodium hydroxide (~5%) prepared from the 25% stock available onsite was used to increase the pH of the RO permeate to a target value of 8. The purpose of this step is to avoid speciation of chloramines into di- or trichloramines, and favor monochloramine, which is more stable and less aggressive to the RO membranes than dichloramine. Formation of



bromamines, which also cause membrane damage, is minimized at higher pH. Since NDMA is known to form faster in the presence of dichloramine (and NDMA precursors), increasing the pH to reduce dichloramine formation is also beneficial.

- 2. Sodium hypochlorite:** 12.5% sodium hypochlorite (free available chlorine) was injected into the 1-gpm carrier RO permeate flow after pH adjustment. A static mixer following chlorine injection ensured homogeneous mixing.
- 3. Ammonium sulfate:** A 40% ammonium sulfate solution was used to inject ammonium into the chlorinated water in a 3:1 Cl:N mass ratio. The 3:1 Cl:N ratio ensures that there is excess ammonia. A static mixer following ammonia addition ensured sufficient mixing for chloramine formation.

After ammonium addition and mixing, the preformed chloramines sidestream was injected into the feed water flow just upstream of a static mixer to achieve a target residual of 3 mg/L as Cl₂.

Sodium hypochlorite dosing into the 1-gpm sidestream was flow-paced based on the feed water flow rate (Meter A in **Figure 5**) and trimmed based on the total chlorine reading after preformed chloramine injection into the main line (Analyzer B in **Figure 5**) to meet the target chloramine residual. Additionally, the free chlorine residual downstream of the chloramine injection point (Analyzer C in **Figure 5**) was used to trim the sodium hypochlorite dose, and/or shut down the sodium hypochlorite pump if free chlorine readings exceed an operator-adjustable setpoint (e.g., >0.3 mg/L). Ammonium sulfate was dosed to maintain a 3:1 Cl:N mass ratio. The system was setup to immediately stop chemical dosing if there was no RO permeate flow in the preformed chloramines sidestream. The total chlorine meter after MF (Analyzer D in **Figure 5**) was not used to control the chloramine dosing but its readings were recorded to determine if there was sufficient chloramine residual entering the RO treatment.

4.2 Water Quality Monitoring

A sampling plan was developed to monitor water quality in the product water and at different points of the treatment. The constituents monitored, sampling locations, frequency of sampling, and analytical method used with the corresponding method detection limits (MDL) and method reporting limits (MRLs) are presented in **Table 2**. Samples were collected as grab samples and sent for analysis to Eurofins Eaton Analytical (Monrovia, CA).

The study had a total operational duration of 12 months. Water quality monitoring started in July 2019 and went through December 2020 with a pause from December 2019 to July 2020, where the AWP Demonstration Facility was shut down for three months due to planned maintenance work in the Ray Stoyer WRF followed by shutdown of the non-critical facilities operation due to reduced workforce during the Covid-19 pandemic. It should be noted that from July 2019 to August 2020, the feed water to the AWP Demonstration Facility was tertiary-treated nitrified secondary effluent from Ray Stoyer WRF. From August 2020 to December 2020, the source water was switched to nitrified secondary effluent from Ray Stoyer WRF for reasons unrelated to this study.



Table 2: Sampling Plan for the Testing of Preformed Chloramines at Padre Dam’s AWP Demonstration Facility.

Analyte	Method	Units	MDL ^(a)	MRL ^(b)	Sample Locations ^(c)	Sampling Frequency
Bromide	EPA 300.0	µg/L	2.2	5.0	AWP Feed ^(d)	Monthly
NDMA	EPA 521	ng/L	0.96	2.0	AWP Feed ^(d)	Monthly
					RO Permeate	Weekly
					RO Feed	Every two weeks
					UV/AOP Effluent	Every two weeks
THMs (Chloroform, Bromoform, DBCM, BDCM)	EPA 524.2	µg/L	0.12 (BDCM) 0.062 (DBCM) 0.14 (Bromoform) 0.11 (Chloroform)	0.5	AWP Feed ^(b)	Monthly
					RO Feed	Weekly
					RO Permeate	Weekly
					UV/AOP Effluent	Weekly
DEHP	EPA 525.2	µg/L	0.15	0.6	RO Feed	Monthly
					RO Permeate	Monthly
					UV/AOP Effluent	Monthly

(a) MDL: Method detection limit

(b) MRL: Method reporting limit

(c) Sample ports are indicated in the drawings in Appendix 1 with blue boxes. Feed Water: SP0, RO permeate: SP23, RO Feed: SP16, UV/AOP Effluent: SP26

(d) Before chloramination

4.2.1 Analytes

Bromide monitoring in the feed water was performed due its potential to form bromamines upon reaction with chlorine and ammonia, as well as the risk that bromamines pose to the integrity of the RO membranes.

Four THMs (bromoform, chloroform, BDCM, DBCM) were monitored. Data from the feed water provided a baseline concentration before preformed chloramine dosing. Samples from the RO feed, RO permeate, and UV/AOP effluent were used to assess THM formation and removal after preformed chloramine dosing and throughout advanced treatment, and to evaluate the CTR compliance of the product water.

NDMA was monitored in the feed water, RO feed, RO permeate, and UV/AOP effluent to confirm the design of the UV/AOP treatment and ensure that no drastic changes in NDMA levels occur.

During one sampling event, triplicate samples were collected from the RO feed and RO permeate and analyzed for THMs and NDMA to assess the variability of the analytical methods.

There was also interest in gathering more data on di(2-ethylhexyl)phthalate (DEHP), which is also regulated under CTR. The sampling performed during this study presented a good opportunity to analyze for DEHP, and for this reason it was added to the sampling plan.



4.2.2 NDMA and THM Reformation

Since the issue of NDMA reformation has been observed after UV treatment when there is a chloramine residual (Farre et al, 2011), this phenomenon was investigated during the study. NDMA reformation may occur if the reactions that take place during UV/AOP result in the formation of NDMA precursors, which then react with the chloramine residual during pipeline transport to the reservoir. Typically, samples for NDMA analysis are immediately quenched to stop any reactions with chlorine. To assess NDMA reformation, UV/AOP effluent was collected and quenched with sodium thiosulfate after a hold time of approximately 1.75 hours. This was done to simulate the conveyance of the product water to Lake Jennings, which is when the NDMA reformation may occur. A total of five samples were collected on different days to assess NDMA reformation. THM reformation was also investigated following a similar procedure.

4.2.3 Feed Water Characterization

At the beginning of the study, a sample of the AWP feed was collected to characterize the general water quality. The following analyses were performed on this sample: bromide ion, alkalinity, total organic carbon (TOC), total dissolved solids (TDS), ammonia, and nitrate. The analyses were performed by Eurofins. Additionally, a UV scan between 200 and 400 nm of the concentrated preformed chloramine solution was performed to confirm that relatively pure monochloramine was formed. The maximum absorption peak for monochloramine is observed at 244 nm, while dichloramine's absorptivity peaks at 297 nm, and trichloramine mainly absorbs at 336 nm.

5 Preformed Chloramines –Study Results

The results and conclusions of the preformed chloramines study are presented in the following sections.

5.1 Preformed Chloramines System – Performance

Chloramines were formed on a sidestream of RO permeate and injected into the AWP feed line prior to MF treatment. The target chloramine dose in the feed water was 3 mg/L as Cl_2 and was monitored in-line with a total chlorine analyzer (Analyzer B in **Figure 5**). During the study, the chloramine residual right after chloramine injection ranged from 2.0 to 3.8 mg/L Cl_2 , with an average of 3.0 mg/L Cl_2 . Chloramines were formed using a Cl:N mass ratio of 3 (i.e., excess ammonia) to ensure that no free chlorine entered the membranes. The measurements from the free chlorine analyzer prior to MF confirmed that there was no free chlorine present. The chloramine residual before RO was also monitored and it ranged from 1.7 to 3.6 mg/L Cl_2 with an average of 2.7 mg/L Cl_2 . The total and free chlorine readings are presented in **Figure 7**.

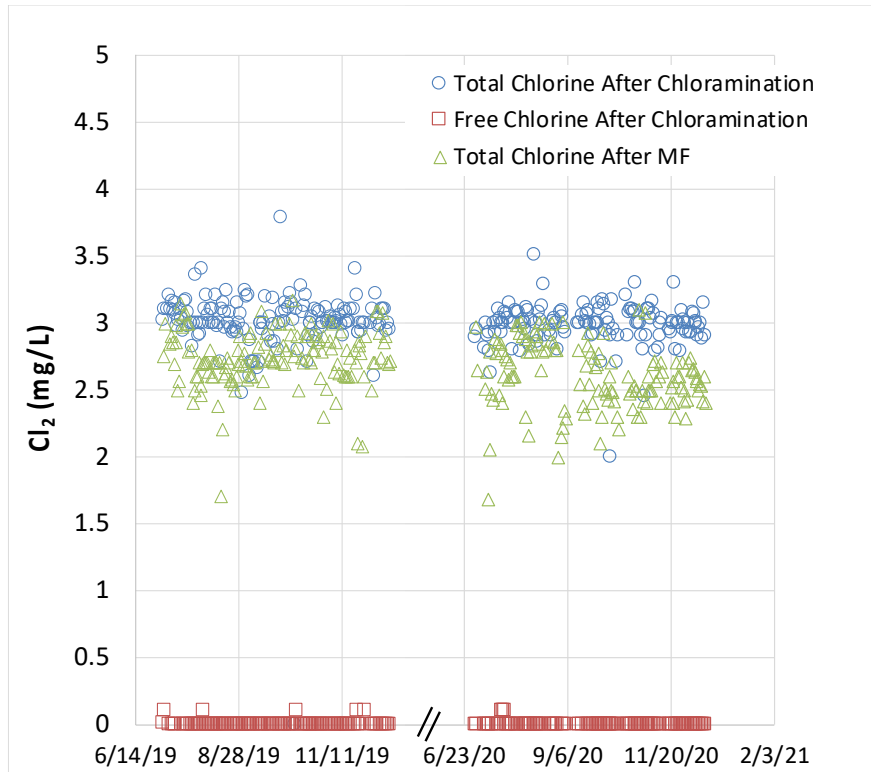


Figure 7: Total and free chlorine monitoring data during the preformed chloramines study.

Dosing of dilute sodium hydroxide was calibrated during the startup of the preformed chloramines system. pH was checked on a daily basis to ensure that it was at or near 8 and the dosing of sodium hydroxide was adjusted as needed. Maintaining the pH of the carrier water near 8 is important to ensure that mainly monochloramine is present. pH in the side-stream ranged from 6.7 to 9.0 with an average of 7.9 (Figure 8).

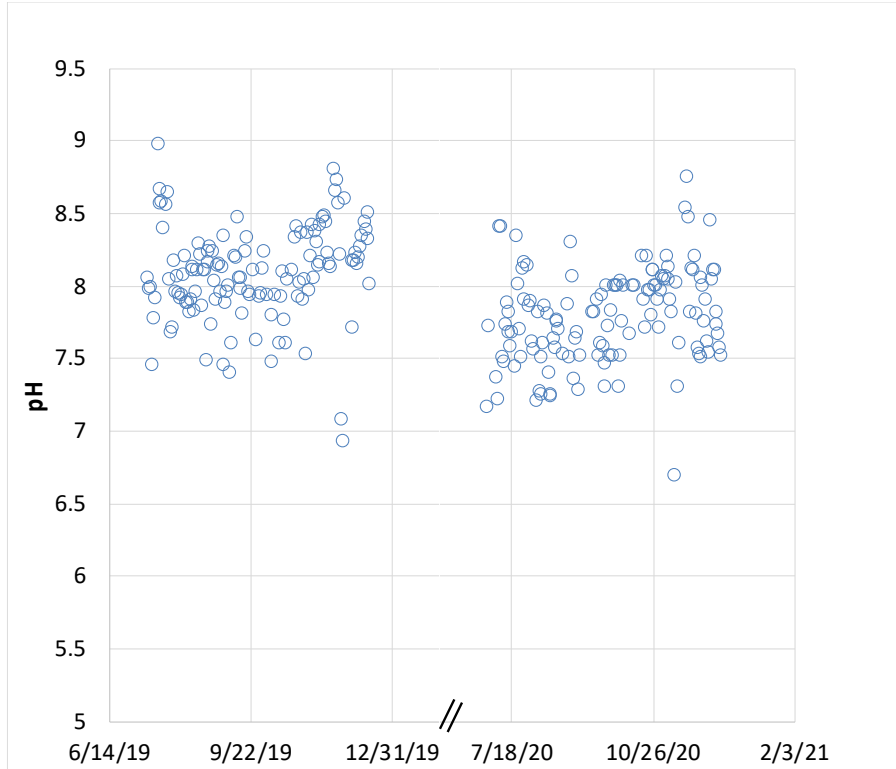


Figure 8: pH of the preformed chloramine sidestream

The speciation of the concentrated preformed chloramines was confirmed by scanning the UV spectrum of the solution between 200 and 400 nm **Figure 9**. A single peak was observed, corresponding to monochloramine.

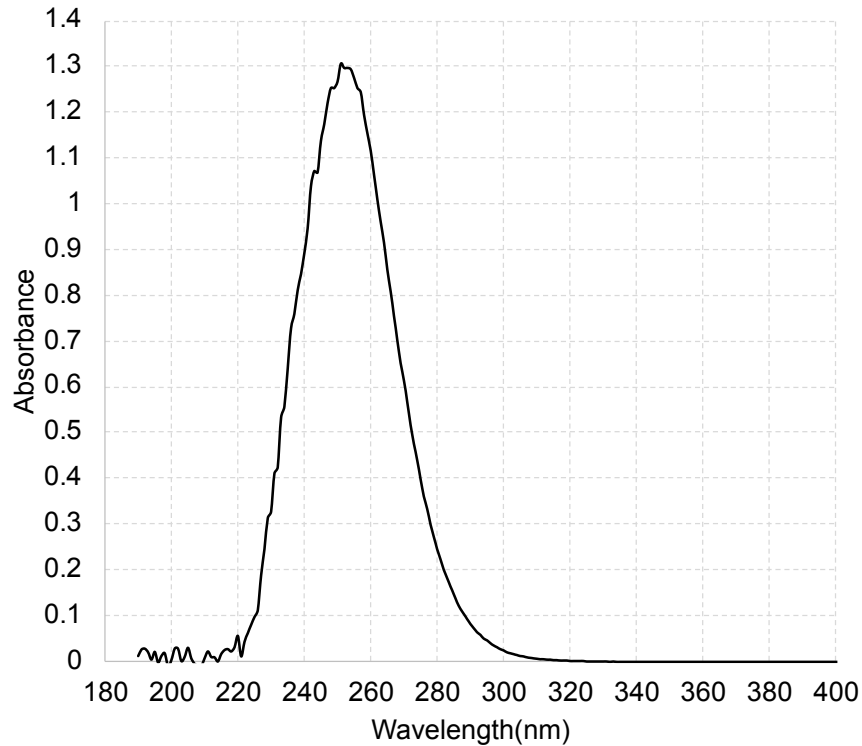


Figure 9: Absorption spectrum of concentrated preformed chloramine solution

5.2 Preformed Chloramines System – Water Quality

5.2.1 Feed Water Quality

Water samples were collected for a period of 12 months following the sampling plan presented in **Table 2**. The complete data set is included in **Appendix 2**. The AWP feed was characterized at the beginning of the study. The results are presented in **Table 3** and are consistent with the level of treatment at the WRF, which consists of secondary treatment with nitrification and denitrification followed by tertiary treatment in denitrification filters with methanol feed.

Table 3: Selected constituents in the AWP feed measured at the beginning of the study.

Constituent	Units	Measurement on 7-18-2019	Range
Nitrate	mg-N/L	8.7	2.7 - 12.4 ^(a)
Bromide	µg/L	270	190 - 300 ^(b)
Alkalinity	mg/L as CaCO ₃	100	--
Ammonia Nitrogen	mg-N/L	0.058	< 1 ^(c)
Total Dissolved Solids	mg/L	580	560 – 660 ^(a)
Total Organic Carbon	mg/L	8.8	6.3 - 8.8 ^(a)

(a) Ranges provided for nitrate, TDS, and TOC are from samples collected during a separate study (CCRO Study) conducted concurrently with the Preformed Chloramines Study.

(b) Ranges for bromide concentration are from monthly samples collected during this study.



(c) The range for ammonia concentration is from samples collected during 2015–2016 Demonstration Study (Padre Dam, 2016).

5.2.2 Bromide

Bromide levels in the AWP feed were monitored for the duration of the study (**Figure 10**). Oxidation of bromide in the presence of free chlorine and the subsequent reaction with ammonia forms bromamines, which could damage the membranes (**Figure 2**). Bromide concentration in the AWP feed ranged from 190 to 300 $\mu\text{g/L}$ and it is expected to be $<100 \mu\text{g/L}$ in the product water (based on other projects with similar treatment and influent bromide concentration). For reference, the average bromide level in U.S. water sources is 100 $\mu\text{g/L}$ and in sea water is 65 mg/L (Luh and Mariñas, 2014). The use of preformed chloramines minimizes the risk of bromamine formation by avoiding direct contact of free chlorine with the AWP feed (see **Figure 3**).

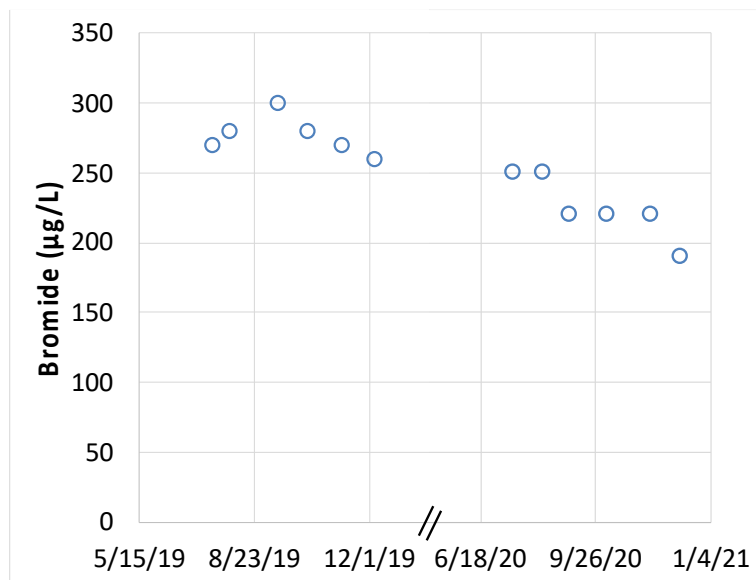


Figure 10: Bromide concentration in the AWP feed

5.2.3 THMs

The results of the monitoring of THMs (BDCM, DBCM, bromoform, and chloroform) along the treatment train and in the UV/AOP effluent are presented in **Figure 11**. Concentrations of DBCM and BDCM in the UV/AOP effluent were used to determine CTR compliance. The analytical method used to measure THMs (EPA 525.2) has an MDL of 0.12 $\mu\text{g/L}$, 0.062 $\mu\text{g/L}$, 0.14 $\mu\text{g/L}$, and 0.11 $\mu\text{g/L}$ for BDCM, DBCM, bromoform, and chloroform, respectively. The MDL represents the minimum concentration that can be distinguished from the method blank. The MRL, which represents the lowest concentration that can be reliably quantified, was 0.5 $\mu\text{g/L}$ for all analytes. The concentration of analytes that were non-detects is reported in **Figure 11** as “less than” the MRL.

BDCM, DBCM, and bromoform were below the MRL in the AWP feed and throughout the advanced treatment. In the UV/AOP effluent, they were consistently below their corresponding MDL. Chloroform was below the MRL in the feed water and sporadically detected in the RO feed, RO permeate, and UV/AOP effluent. Note that during the 2015-2016 sampling, when free



Preformed Chloramines for CTR Compliance

chlorine disinfection of AWP feed followed by conventional chloramination were in place, the average concentrations of BDCM and DBCM were in the order of 5.4 µg/L and 0.76 µg/L, respectively. The results obtained for BDCM and DBCM indicate that using preformed chloramines effectively minimizes the formation of these two THMs during advanced treatment, resulting in a product water that complies with the CTR standards for these constituents.

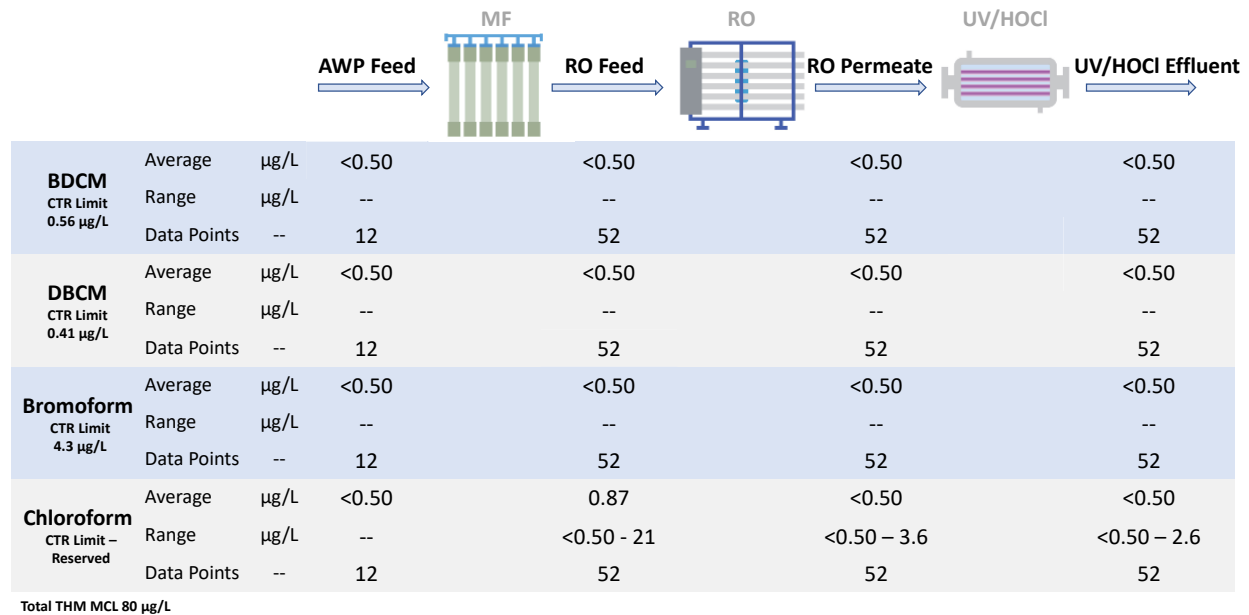


Figure 11: THM monitoring results along the AWP treatment.

5.2.4 NDMA

NDMA concentrations are presented in **Figure 12**. NDMA was detected in the AWP feed water at median value of 8.05 ng/L. As expected, no removal was observed through MF treatment and partial removal was observed through RO treatment with a median concentration in the RO permeate of 5.25 ng/L. NDMA was effectively removed with ultraviolet treatment to levels below the MRL of 2 ng/L. In fact, in the UV/AOP effluent NDMA was consistently below the MDL of 0.96 ng/L.

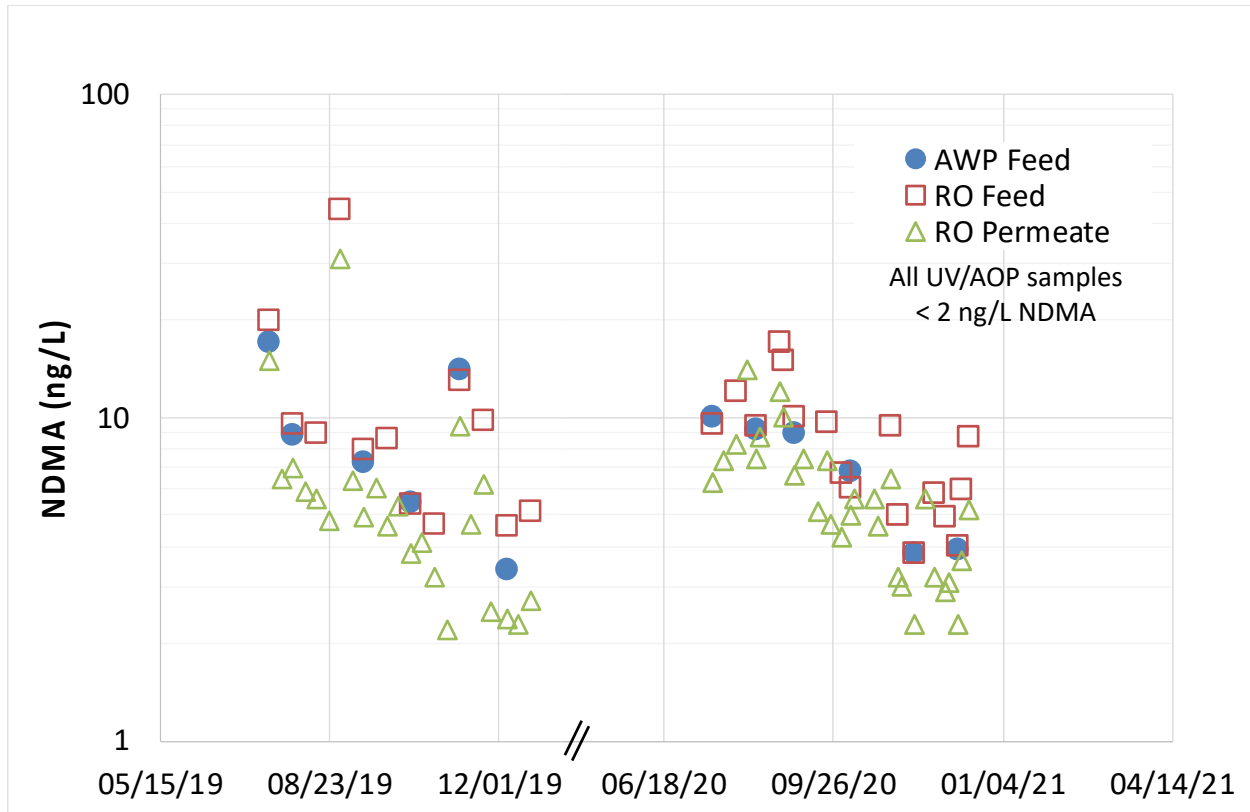


Figure 12: NDMA concentrations along the AWP treatment.

5.2.5 NDMA and THM Reformation

NDMA and THM reformation was assessed on five samples of UV/AOP effluent by measuring their concentration right after collection (t=0 or Initial) and after 1.75 hours (Final). The results are presented in **Table 4**. In all five samples, NDMA and THMs were below detection at t=0 and they remained below detection after the 1.75-hour incubation, indicating that no detectable reformation occurred.

Table 4: Assessment of NDMA and THM reformation in UV/AOP product water

Constituent (a)	Units	11/24/20		12/1/20		12/8/20		12/10/20		12/15/20	
		Initial	Final (b)	Initial	Final (b)	Initial	Final (b)	Initial	Final (b)	Initial	Final (b)
BDCM	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
DBCM	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Bromoform	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chloroform	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
NDMA	ng/L	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0

(a) Non-detects were reported as less than the corresponding MRL. It is worth noting that NDMA was below the MDL (0.96 ng/L) for all sampling events.

(b) After 1.75 hours



5.2.6 Method Variability

To assess the variability in the methods used to quantify NDMA and THMs, triplicate samples collected on the same sampling event were analyzed. The results are presented in **Table 5** and indicate that the methods are consistent in their performance and the measurements have a low relative standard deviation (RSD).

Table 5: Results of triplicate measurements on RO feed and RO permeate samples to assess method variability.

Constituent	Method	RO Feed		RO Permeate	
		Triplicate Measurements	Average ± Standard Deviation & RSD	Triplicate Measurements	Average ± Standard Deviation & RSD
BDCM (µg/L)	EPA 524.2	<0.50	<0.50	<0.50	<0.50
		<0.50		<0.50	
		<0.50		<0.50	
DBCM (µg/L)	EPA 524.2	<0.50	<0.50	<0.50	<0.50
		<0.50		<0.50	
		<0.50		<0.50	
Bromoform (µg/L)	EPA 524.2	<0.50	<0.50	<0.50	<0.50
		<0.50		<0.50	
		<0.50		<0.50	
Chloroform (µg/L)	EPA 524.2	0.53	0.54 ± 0.01 RSD = 1.1%	<0.50	<0.50
		0.54		<0.50	
		0.54		<0.50	
NDMA (ng/L)	EPA 521	5.8	5.73 ± 0.06 RSD = 1%	3.2	3.43 ± 0.21 RSD = 6.1%
		5.7		3.6	
		5.7		3.5	

5.2.7 DEHP Monitoring

Samples of the RO feed, RO permeate and UV/AOP effluent were analyzed for DEHP. A total of 12 samples for each location were analyzed and a summary of the results is presented in **Table 6**. The complete data set for DEHP is included in **Appendix 2**. The DEHP concentration in all the UV/AOP samples was below 0.6 µg/L, which is well below its CTR limit of 1.8 µg/L.

Table 6: DEHP measurements in RO feed, RO permeate, and UV/AOP effluent

	RO Feed	RO Permeate	UV/AOP Effluent
Average (µg/L)	< 0.60	< 0.60	< 0.60
Range (µg/L)	< 0.60 – 0.80	< 0.60 – 0.66	< 0.60
No Data Points	12	12	12



6 Conclusions and Recommendations

The data collected at the AWP Demonstration Facility to evaluate the effectiveness of preformed chloramines indicate that preforming chloramines in RO permeate before injecting into the AWP feed helps maintain DBP levels below CTR thresholds. Particularly, BDCM and DBCM were consistently below the method reporting limit (0.50 µg/L) and detection limit (0.12 µg/L for BDCM and 0.062 µg/L for DBCM) in the UV/AOP effluent during the study. NDMA is removed during RO and UV/AOP and consistently below detection (<0.96 ng/L) in the UV/AOP effluent and there was no evidence of reformation after UV treatment.

Implementation of preformed chloramines does not require specialized training or equipment and it uses chemicals that will be already in place at the site. It also requires minimal additional equipment compared to the in-line chloramination option (static mixers, pump for carrier water). The benefits of implementing preformed chloramination are significant as it offers the possibility of controlling formation of DBPs that are subject to regulatory compliance (DBCM, BDCM, NDMA) or that may pose operational challenges (bromamines).

This research project demonstrated that the preformed chloramines approach can be a simple, cost-effective solution to comply with CTR limits for THMs in the purified effluent. Mixing preformed chloramines in the AWP influent is a method which retains biofouling control while preventing the formation of THMs by preforming the chloramines in a clean RO permeate sidestream (low in disinfection byproduct precursors). Therefore, by preventing the formation of THMs, this allows the surface water augmentation projects to comply with the extremely low effluent limits set forth by the CTR. This approach offers far less infrastructure and capital costs than the air stripping alternative: forming these compounds with the traditional chloramine pretreatment and subsequently stripping them out of the water.

This study proved successful implementation of the preformed chloramines approach to make surface water augmentation more attainable in California by reducing the costs associated with CTR compliance. Through the validation of this cost-effective solution to comply with strict effluent CTR limitations in receiving reservoirs, this research will reduce barriers to the implementation of surface water augmentation in California.

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Preformed Chloramines for CTR Compliance

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Appendix 1 – Test Plan



Technical Memorandum
Padre Dam Advanced Water Purification Demonstration Facility
Test Plan for Demonstration of Preformed Chloramines for California
Toxics Rule Compliance

Draft Date: May 23, 2019

To: **Padre Dam Municipal Water District**
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Subject: **Test Plan for Demonstration of Preformed Chloramines**
for California Toxics Rule Compliance

1. Introduction

The East County Advanced Water Purification Program (ECAWP Program) was developed in partnership with Padre Dam Municipal Water District (Padre Dam), Helix Water District, the County of San Diego, and the City of El Cajon to provide East San Diego County with a new source of local, reliable, drought-proof water for potable use. Together, these four agencies are pursuing a surface water augmentation (SWA) potable reuse project. Advanced treated water (purified water) will be produced at the Advanced Water Purification Facility via full advanced treatment of tertiary effluent from the Ray Stoyer Water Reclamation Facility. The original design of the advanced treatment involves free chlorine disinfection of tertiary effluent, and subsequent ammonia addition for formation of chloramines followed by membrane filtration (MF), reverse osmosis (RO) and ultraviolet advanced oxidation (UV/AOP) with free chlorine. After treatment, the purified water will be discharged to Lake Jennings, a local reservoir which serves

as a water source for the R.M. Levy Water Treatment Plant (WTP), owned by Helix Water District. The drinking water from the WTP will then be distributed to Helix Water District's service area, which also includes Padre Dam, Otay, and Lakeside Water Districts.

Free chlorine disinfection of tertiary effluent can lead to significant formation of chlorinated disinfection byproducts (DBPs) such as trihalomethanes (THMs) and haloacetic acids (HAAs) due to the presence of sufficient inorganic and organic DBP precursors that can react with chlorine in the tertiary effluent. Discharges to Lake Jennings have to comply with the California Toxics Rule (CTR) (40 CFR), which establishes stringent limits for two THMs: bromodichloromethane (BDCM) and dibromochloromethane (DBCM). Once formed, THMs are reduced but not entirely removed by advanced treatment. When the original process train was first conceived, the goal was groundwater augmentation and modest levels of DBPs were acceptable, but in the project's present form with discharge to Lake Jennings, much lower DBP levels must be achieved in order to meet the CTR. Therefore, it is preferable to prevent their formation. This can be achieved by removing all free chlorine contact with the feed water. However, it is still necessary to maintain a chloramine residual for membrane biofouling control.

This project will evaluate the effectiveness of dosing chloramines that were preformed in a sidestream of carrier water with low levels of THM precursors, i.e., RO permeate. The preformed chloramines will then be injected into the MF feed water (tertiary effluent) line to prevent biofouling of process membranes while minimizing THM formation. This will result in purified water that is CTR-compliant.

This technical memorandum provides a test plan for the preformed chloramines system at Padre Dam's Advanced Water Purification Demonstration Facility (AWP Demo). The test plan includes a sampling plan and schedule, and a description of the modifications that Trussell Technologies (Trussell) will perform at the AWP Demo so that the performance of the preformed chloramines approach can be evaluated.

2. Background

Padre Dam's Advanced Water Treatment Program is designed as a SWA project which will discharge purified water to Lake Jennings. Federal and State regulations establish limits for DBPs, including THMs, formed during free chlorine disinfection. THMs are formed by the reaction of free chlorine with naturally occurring organic and inorganic (e.g., bromide) matter in the water. The limit for total THMs, which is calculated as the sum of the four regulated THMs (chloroform, BDCM, DBCM, and bromoform), is 80 µg/L. CTR, which applies to discharges to Lake Jennings, has lower limits for BDCM (0.56 µg/L) and DBCM (0.41 µg/L).

The treatment train at the AWP Demo consists of free chlorine disinfection of tertiary effluent and subsequent ammonia addition for formation of chloramines,

followed by advanced treatment with MF, a two-stage RO train, advanced oxidation process (AOP) with UV radiation and sodium hypochlorite addition. The facility has a production capacity of 100,000 gallons per day (gpd). Data collected at the AWP Demo indicates that DBCM and BDCM are formed during free chlorine disinfection and are moderately removed throughout the treatment train but not enough to bring residuals within CTR compliance.

Since additional treatment options for removing THMs (e.g., air stripping) imply high capital and operational costs, prevention of THM formation is a more effective approach. This requires avoiding contact of free chlorine with THM precursors, which means that free chlorine disinfection of the tertiary effluent should not take place. However, chloramination, which is achieved by addition of chlorine and ammonia, is still necessary to provide biofouling control for the MF and RO processes. Even a short contact time between free chlorine and tertiary effluent could result in the formation of THMs, especially if bromide is present in the water. Alternatively, chloramines can be preformed in water with low levels of THM precursors, such as RO permeate, and then dosed into the tertiary effluent.

RO treatment provides high rejection of organics, which can be measured as total organic carbon (TOC). Due to the low TOC concentration in RO permeate, addition of free chlorine to RO permeate is expected to result in minimal formation of THMs. Thus, preforming chloramines in RO permeate water and dosing it upstream of the MF system provides a cost-effective strategy for CTR compliance that could be easily implemented as it requires few modifications to the design and uses chemicals that are already onsite.

Chloramination could potentially form *N*-Nitrosodimethylamine (NDMA) through the reaction of chloramines with nitrogen-containing organic matter in the water. In California, NDMA has a Notification Level of 10 ng/L, and a CTR limit of 0.69 ng/L. Even though it has been shown that the use of preformed chloramines decreases NDMA formation in advanced treatment purification systems (Mitch et al., 2005), monitoring of NDMA will be performed when evaluating the preformed chloramines approach to ensure the robustness of the system to abate any NDMA loading variations and achieve regulatory compliance. Additionally, NDMA is readily removed via photolysis during UV treatment.

Another compound of interest for the Padre Dam project is bis(2-ethylhexyl) phthalate (DEHP). This compound is used in the production of PVC and is regulated under CTR with a limit of 1.2 µg/L. Additional data is needed to confirm its absence in the purified water. Previous experience suggests that DEHP analysis is prone to false positives so additional measures will be taken to minimize this possibility.

Bromide should also be monitored while dosing preformed chloramines, not only because it is a THM precursor, but also because chlorine reacts rapidly to oxidize bromide to bromine leading to brominated DBPs, as well as to formation of

bromamines, rather than chloramines, when ammonia is added. Bromamines oxidize RO membranes significantly faster than chloramines, shortening their service lifetime and increasing overall operation and maintenance costs.

3. Preformed Chloramines System Approach and Sampling

This section describes the design of the preformed chloramines dosing system and the sampling plan and methods that will be used to evaluate the performance of the approach.

3.1 Preformed Chloramines System

The preformed chloramines system will consist of a sidestream that will utilize RO permeate as carrier water with three injection ports in series for sodium hydroxide, sodium hypochlorite, and ammonium sulfate. The RO carrier water flow will be set constant at 1 gallon per minute (gpm). The modifications to install the preformed chloramines dosing system in the AWP Demo are indicated as markups in the drawings in Appendix A. The three chemicals are already available at the AWP Demo and the operators are trained to handle them.

The sequence of chemical addition will be as follows:

1. **Caustic soda (sodium hydroxide):** a dilute solution of sodium hydroxide prepared from the 25% stock available onsite will be used to increase the pH of the RO permeate to a target value of 8. The purpose of this step is to avoid speciation of chloramines into di- or trichloramines, and favor monochloramine, which is more stable and less aggressive to the RO membranes than dichloramine. Formation of bromamines, which also cause membrane damage, is minimized at higher pH. Since NDMA is known to form faster in the presence of dichloramine (and NDMA precursors), increasing the pH to reduce dichloramine formation is also beneficial to avoid NDMA formation. pH will be monitored via an online pH probe.
2. **Sodium Hypochlorite:** 12.5% sodium hypochlorite (free available chlorine) will be injected into the 1 gpm carrier RO permeate flow after pH adjustment. The maximum concentration in the carrier water will be 1,000 mg/L as Cl₂. A static mixer (Static Mixer 3) will be placed following chlorine injection to ensure homogeneous mixing.
3. **Ammonium sulfate:** A 40% ammonium sulfate solution will be used to inject ammonium into the chlorinated water in a 3:1 Cl₂:N mass ratio. A static mixer (Static Mixer 4) will follow the ammonium injection to ensure sufficient mixing for chloramine formation.

After ammonium addition and mixing, the preformed chloramines sidestream will be injected into the feed water flow just upstream of Static Mixer 2, before the

chlorine contactor (see drawings in Appendix A). The chloramine concentration in the carrier line will vary depending on the desired dose and the feed flow and will not exceed 1,000 mg/L as Cl₂. Bypassing the chlorine contactor would require significant modifications to the current installation. Instead, the chloraminated water will be allowed to flow through the contactor. This is not expected to present issues regarding potential formation of DBPs because of the short residence time. A monochloramine dose of 3 to 5 mg/L as Cl₂ will be applied in the feed water to maintain 3.0 mg/L as Cl₂ total chlorine residual.

The necessary modifications to the AWP Demo as well as the control settings and programming changes required for preformed chloramines dosing are described in Section 4.

3.2 Sampling Plan and Analytical Methods.

During the startup of the preformed monochloramine system, a UV spectrometer will be brought on-site to scan the UV spectrum of the chloramines formed and confirm that relatively pure monochloramine is formed. The spectrum will be measured between 200 and 400 nm, since the maximum absorption peak for monochloramine is observed at 244 nm, while dichloramine's absorptivity peaks at 297 nm, and trichloramine mainly absorbs at 336 nm.

Once the preformed chloramines dosing starts, select water quality parameters will be monitored for a period of 12 months to ensure sufficient information is collected to evaluate effectiveness of the approach. The constituents to be analyzed, the sampling locations and frequency, and analytical methods and their respective method reporting limits (MRLs) are presented in **Table 1**. Grab samples will be collected by Trussell staff and shipped in coolers with ice packs for analysis by Weck Laboratories, in City of Industry. All sample bottles will be provided by Weck Labs. No samples will be submitted to Padre Dam's Water Quality Laboratory for analysis.

Bromide will be monitored in the feed water because of its potential to form bromamines upon reaction with chlorine and ammonia, as well as the risk that this poses to the integrity of the membranes.

Four THMs (bromoform, chloroform, BDCM, DBCM) will be monitored during the study. Data from the feed water will provide a baseline concentration before preformed chloramine dosing. Samples from the RO feed, RO permeate, and UV/AOP effluent will be used to assess THM formation and removal after preformed chloramines dosing and throughout advanced treatment, and to evaluate the CTR compliance of the product water.

A sample of the feed water will be collected during the installation of the preformed chloramines dosing system (May/June 2019) and analyzed for bromide ion, alkalinity, pH, TOC, total dissolved solids (TDS), ammonia, nitrate,

nitrite, and THMs. These samples will be analyzed by Weck Labs or at Trussell’s laboratory in Pasadena, CA.

NDMA will be monitored in the feed water, RO feed, RO permeate, and UV/AOP effluent to confirm the design of the UV/AOP treatment and ensure that no drastic changes in NDMA levels occur.

DEHP monitoring will take place at the RO feed, RO permeate, and UV/AOP effluent. Field blanks in which a sample of deionized water is handled similarly to the samples will be used to rule out false positives.

Table 1: Sampling plan and analytical methods.

Analyte	Method	MRL (µg/L)	Sample Location(s)	Sample Port ID*	Type	Sampling Frequency
Bromide	EPA 300.0	10	Feed Water	SP0	Grab sample	Monthly
NDMA	EPA 521	0.002	Feed Water	SP0	Grab sample	Monthly
			RO Permeate	SP23		Weekly
			RO Feed	SP16		Every two weeks
			UV/AOP Effluent	SP26		Every two weeks
THMs (Chloroform, Bromoform, DBCM, BDCM)	EPA 524.2	0.5	Feed Water	SP0	Grab sample	Monthly
			RO Feed	SP16		Weekly
			RO Permeate	SP23		Weekly
			UV/AOP Effluent	SP26		Weekly
DEHP	EPA 525.2	3.0	RO Feed	SP16	Grab sample	Monthly
			RO Permeate	SP23		Monthly
			UV/AOP Effluent	SP26		Monthly

*Sample ports are numbered following drawings presented in Appendix A and are indicated with blue boxes.

4. Modifications to the Demonstration Facility

4.1 Proposed Modifications

The modifications to install the preformed chloramines dosing system in the AWP Demo are indicated as markups in the drawings in Appendix A.

RO permeate from the RO product tank will serve as the carrier water for the preformed chloramines. A portion of the RO permeate delivered to the UV/AOP process by the RO permeate pump will be diverted to the preformed chloramines system with ½” CPVC piping. The pressure provided by the RO permeate pump will be used to pump the carrier water at 1 gpm and the flow will be regulated with a manual ball valve and a variable area flowmeter (rotameter). In addition, a pressure switch will be installed in the ½” carrier water line.

As the RO permeate flows through the sidestream line, dilute caustic solution, sodium hypochlorite, and ammonium sulfate will be dosed, in that order. The order of injection is important to ensure formation of pure monochloramine. pH has to be increased to 8 before the addition of sodium hypochlorite and ammonia to prevent the formation of dichloramine. The existing chemical tanks and metering pumps will be used to dose ammonium sulfate and sodium

hypochlorite. An additional 55-gallon storage tank (with a containment pallet) and chemical metering pump will be installed to deliver caustic solution. Their location is indicated in the drawings in the Appendix A. Dosing of the caustic solution will be calibrated during installation and a procedure will be developed for periodic adjustment. A pH sensor will be installed in the preformed chloramine line between the caustic and the sodium hypochlorite injection points. The pH sensor is for monitoring purposes only. A static mixer will be installed downstream of the sodium hypochlorite and ammonium sulfate injection points (Static Mixers 3 and 4, respectively) to ensure uniform mixing and reaction of the chemicals. The maximum chloramine concentration in the sidestream line will be 1,000 mg/L as Cl₂. The preformed chloramines will be dosed into the feed water line at the existing free chlorine addition point upstream of Static Mixer 2, targeting a total chlorine residual of 3 mg/L as Cl₂.

The free ammonia analyzer in the feed water line will be re-plumbed to monitor free ammonia residual after preformed chloramine injection into the feed water line. The free ammonia residual will serve as a control point to ensure no free chlorine is present in the feed water. The existing free chlorine analyzer (AE-102) will be replaced with a total chlorine analyzer. Total chlorine residuals measured by AE-102 will serve as the process variable for the chlorine dosing pump.

The ORP sensor currently located downstream of the MF Product tank will be relocated upstream of the tank to allow for increased response time, in the event that free chlorine is present in the water.

4.2 Parts and Equipment

The parts and equipment that will be used to perform the modifications to the AWP Demo are presented in **Table 2**.

Table 2: Parts and equipment needed to install the preformed chloramines dosing system.

Part	Brand/Model	Qty	Catalog #	Vendor
Total Chlorine Analyzer	CL10sc	1	LXV45B.99.11022	HACH
Sample taps	Asahi America labcock ball valves MTxHose	3	1078002	Harrington
NaOH batch day tank	Premium vertical open top tank 55 gallon	1	01-306-36	Harrington
Bulk head for day tank	Hayward BFAS 1/2"	1	BFAS1005CFS	Harrington
Static mixer	Koflo threaded CPVC static mixer	2		Harrington
Calibration column	Griffco 30 mL column	1	CCG-0030-P	griffcovalve.com
Containment pallet	Eagle 1620 2 drum 66 gallons containment	1	T9F337471	globalindustrial.com
Inline rotameter	Blue-white F-440 L series	1	F-44376L-8	Harrington
Injection quill	Koflo 1/2" diameter 3" long	1		Harrington
CPVC tee	1/2" SCH 80 SxSxT	5	802C-005	Harrington
CPVC ell	1/2" SCH 80 SxS	5	806C-005	Harrington

Part	Brand/Model	Qty	Catalog #	Vendor
CPVC union	1/2" SCH 80 SxS	2	897C-005	Harrington
CPVC nipple	1/2" SCH 80 x 2"	4	882C-020	Harrington
CPVC ell	1/2" SCH 80 SxT	3	807C-005	Harrington
CPVC ell	1/2" SCH 80 threaded	4	808C-005	Harrington
Compression male adapter	1/4" x 1/4" PVDF	6	10-4-4-K-PG	Harrington
CPVC threaded bushing	1/2" x 1/4" SCH 80	4	839C-072	Harrington
Pump for NaOH	Blue-White A-100N FlexFlo	1	A1N10V-4T	Harrington
Pressure switch	Wika CSM01 series	1		
Chemical injection ball valves	Asahi America Omni ball valves	6	1070003	Harrington
1/2" spring check valves	Praher Plastics S4	3	3-050C-VT	Harrington
1/2" check valve	Hayward TC	1	TC10050ST	Harrington
1/2" pipe	any CPVC SCH 80	40 ft	800C-005	Harrington
pH sensor	pHD sc	1	DPD1P1	HACH

4.3 Control Narrative

In order for the caustic solution, sodium hypochlorite, and ammonium sulfate metering pumps to work and inject solution into the carrier water line, all of the following conditions have to be satisfied:

- There is sufficient feed water flow as measured by the influent water flow meter (FE-101);
- The pressure switch downstream of the RO permeate pump is energized; and
- The water level in the RO product tank is above the low-level setting as indicated by the measurement from the level sensor, LSL-302 de-energized.

Failure to comply with any of these conditions should result in immediate shutdown of the three chemical metering pumps (sodium hypochlorite, ammonium sulfate, and sodium hydroxide) to avoid the injection of concentrated chloramines to an empty carrier water line or feed water line.

Sodium hypochlorite dosing into the 1 gpm carrier water line will be flow-paced based on the feed water flow rate (FE-101). Two additional levels of control will be implemented:

- Total chlorine measurement: sodium hypochlorite dosing will be trimmed based on the total chlorine reading to meet the target chloramine residual.



- Free-chlorine measurement: free chlorine residual downstream of the chlorine contactor (AE-103) will be used to trim down the sodium hypochlorite dose, and/or shut down the sodium hypochlorite pump if free chlorine readings exceed an operator-adjustable setpoint (e.g., >0.3 mg/L).

Ammonium sulfate dosing will be flow-paced based on the feed water flow rate (FE-101) and the range will be computed to maintain a 3:1 Cl₂:N mass ratio. An additional level of control will be provided by the ammonia analyzer downstream of the preformed chloramines injection. If the free ammonia measurement is below 0.2 mg/L as N, the ammonium sulfate dosing will be increased to meet the target residual. Additional alarms could be triggered to notify operators if free ammonia residuals drop for extended periods of time.

Further protection of the RO membranes could be achieved by moving the ORP sensor located in the effluent of the MF product tank upstream of the tank. This will provide greater response time to potential free chlorine and bromamine exposure and help reduce the risk to the RO membranes' integrity. Moving of the ORP sensor is an optional redundant step to supplement the free chlorine sensor.

The sodium hydroxide pump will be tied to the same run bit as the ammonium sulfate and sodium hypochlorite pumps. Any event that triggers a shutdown of the ammonium sulfate and sodium hypochlorite pumps should trigger a shutdown of the sodium hydroxide pump as well. This control logic will prevent waste of chemicals and ensure that the sidestream line will not be obstructed by chemical deposits.

Trussell will coordinate with plant operators and the selected programmer for modifications to the AWP Demo controls. Trussell has noted that Padre Dam has a preference to have the Biwater programmer who previously coded the controls of the RO skid make these changes, and secondarily to have Padre Dam's SCADA programmer make the changes.

5. Reporting

A Summary of Performance Report will be submitted in December 2019 (approximately midway through the project) to communicate to Padre Dam the preliminary findings of the project and inform the Design-Build Request for Proposals. In addition, once the project is completed a Draft Final Report will be developed to summarize the project and present all observations and conclusions from the monitoring study. This report will include the CTR water quality data and present the outcomes of the analysis of the impact on CTR constituents of the preformed chloramines strategy. Conclusions will be presented discussing the applicability of preformed chloramines for advanced treatment and SWA. The draft will be submitted to Padre Dam in early 2021 and the report will be finalized in February 2021.



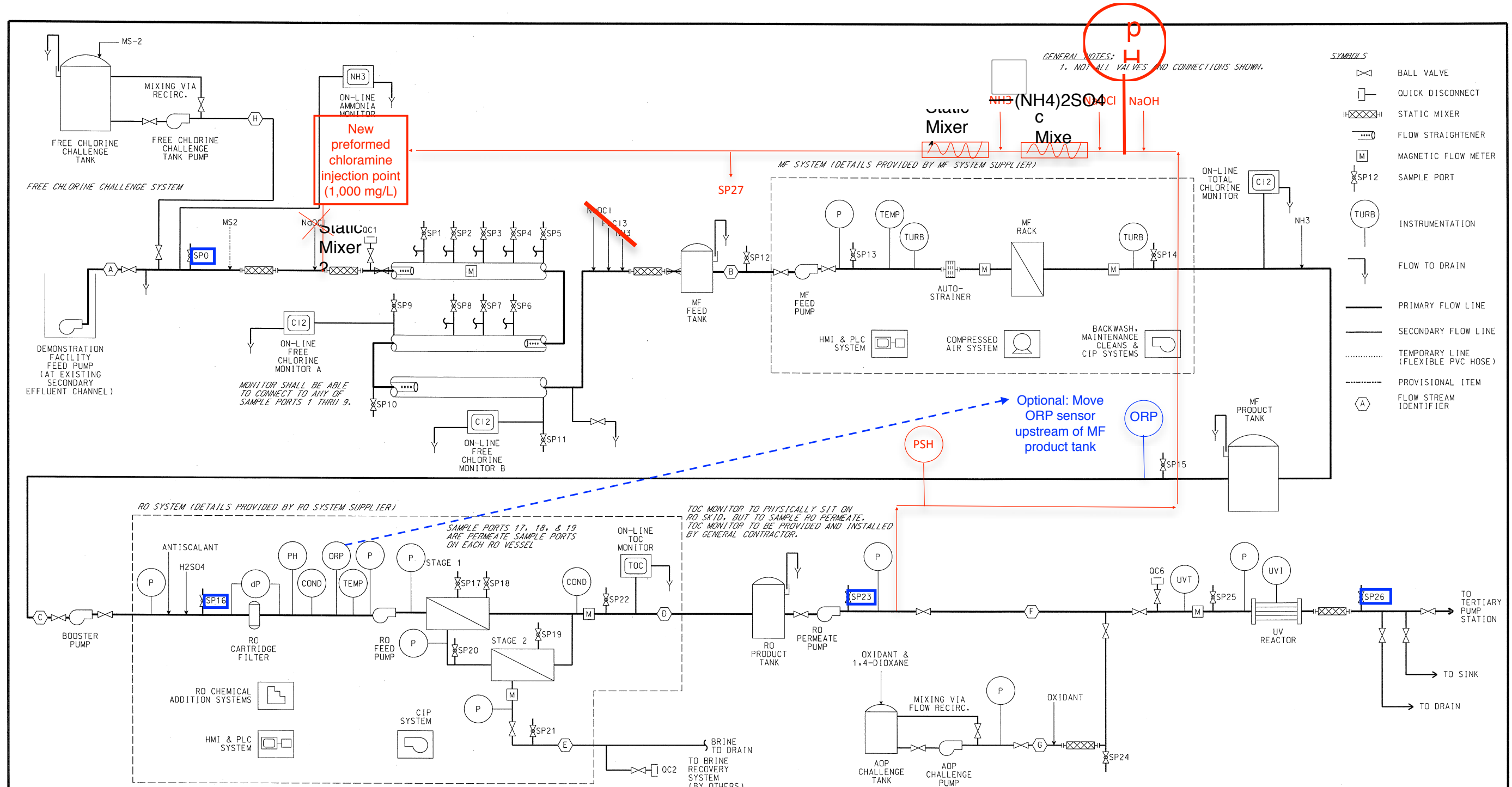
7. References

40 CFR – Code of Federal Regulations. 2000. Part III – EPA. Part 131 – Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California; Rule. Federal Register.

Mitch, W.A.; Oelker, G. L.; Hawley, E. L.; Deeb, R.A.; Sedlak, D.L. 2005. Minimization of NDMA Formation during Chlorine Disinfection of Municipal Wastewater by Application of Pre-Formed Chloramines. Environmental Engineering Science VOL. 22, NO. 6

Appendix A

Blue boxes indicate ports that will be used for sample collection. Refer to Table 1 for detailed sampling schedule.
Optional modifications indicated in Blue



STREAM	DESCRIPTION	FLOW (GPM)
A	AWP FEED	90-105
B	MF SYSTEM FEED	90-100
C	RO SYSTEM FEED	86-95
D	RO SYSTEM PRODUCT	70-75
E	RO SYSTEM BRINE	12-23
F	UV SYSTEM FEED (TITLE 22)	70
G	AOP CHALLENGE FLOW	10-40
H	FREE CHLORINE CHALLENGE	70-90

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Trussell
TECHNOLOGIES INC

DRAWING REFERENCES:

SIGNATURE OF THESE PLANS IS NOT A COMMITMENT TO SERVE		
REV	DATE	DESCRIPTION

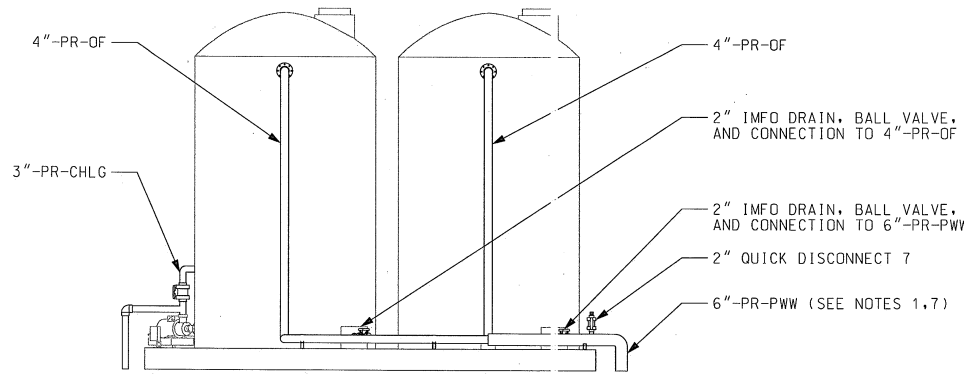
DESIGN BY: RST/BMP DRAWN BY: EYI
RECOMMENDED BY: ARNE S. CHECKED BY: RST/BMP

PADRE DAM MUNICIPAL WATER DISTRICT

AWP DEMONSTRATION FACILITY PROCESS FLOW DIAGRAM

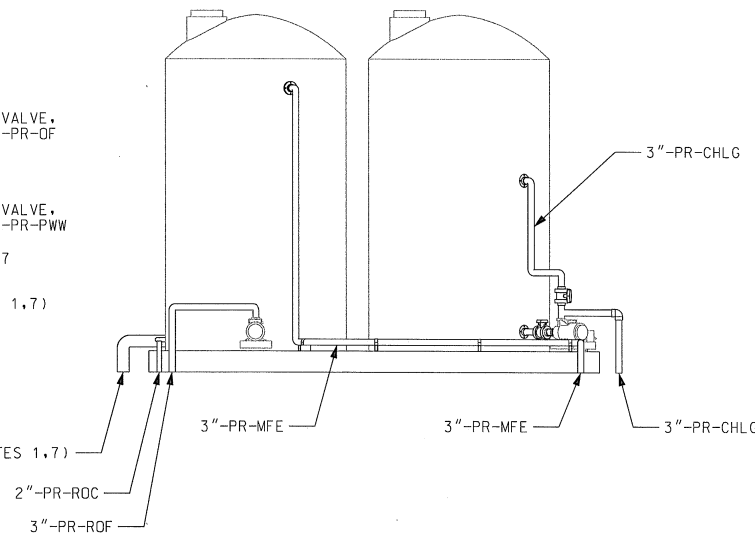
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G-3



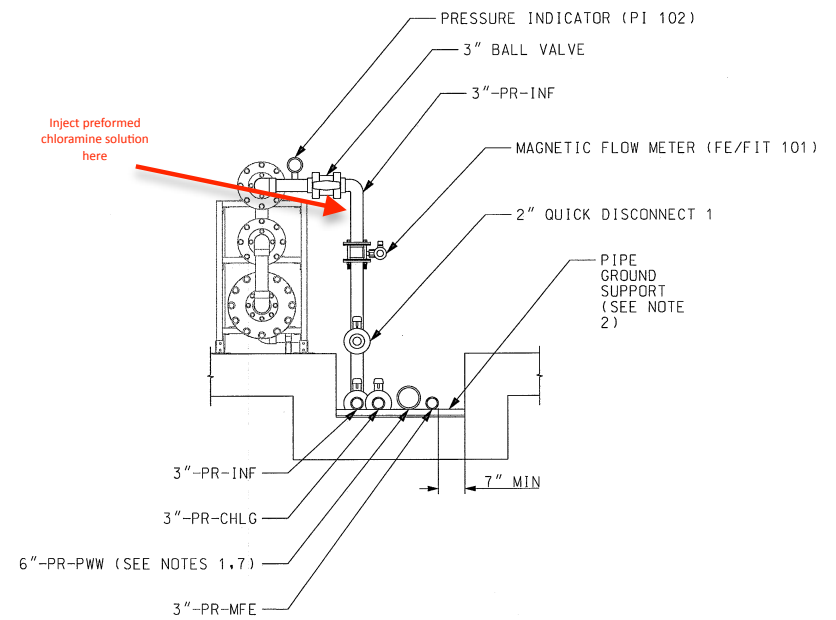
TANK PIPING (WEST)
SCALE: 1/4" = 1'-0"

A
M-2



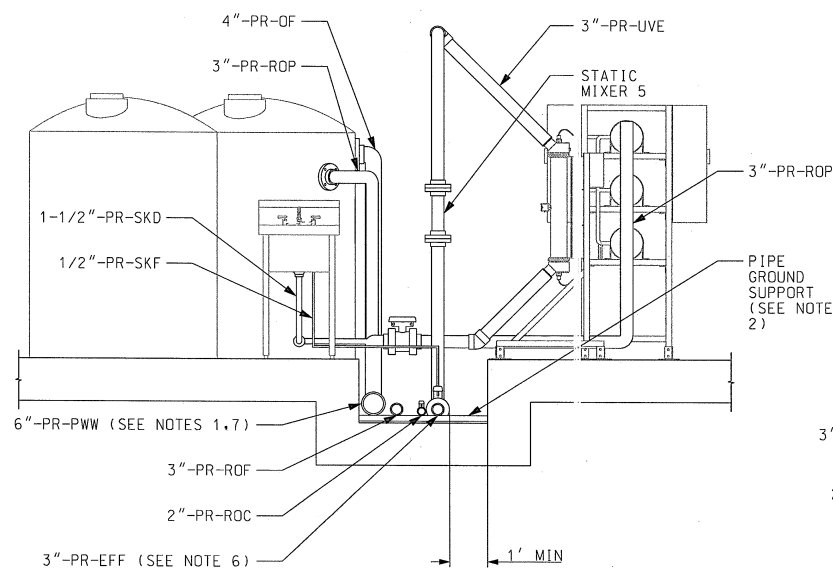
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B
M-2



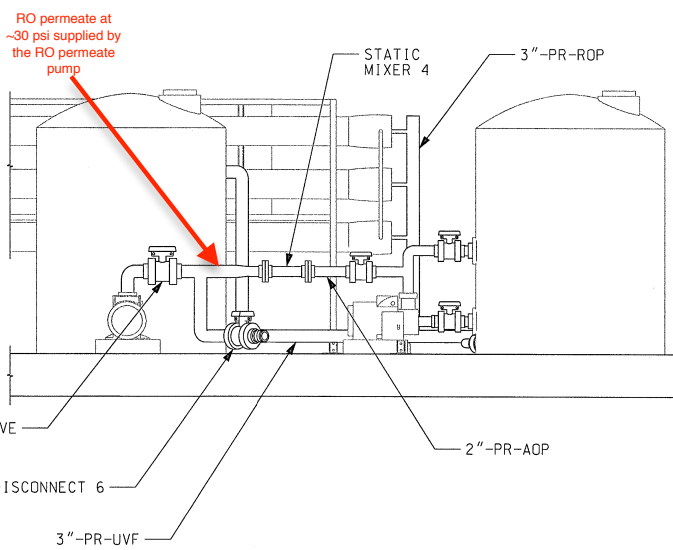
NORTH TRENCH SECTION (WEST)
SCALE: 1/2" = 1'-0"

C
M-2



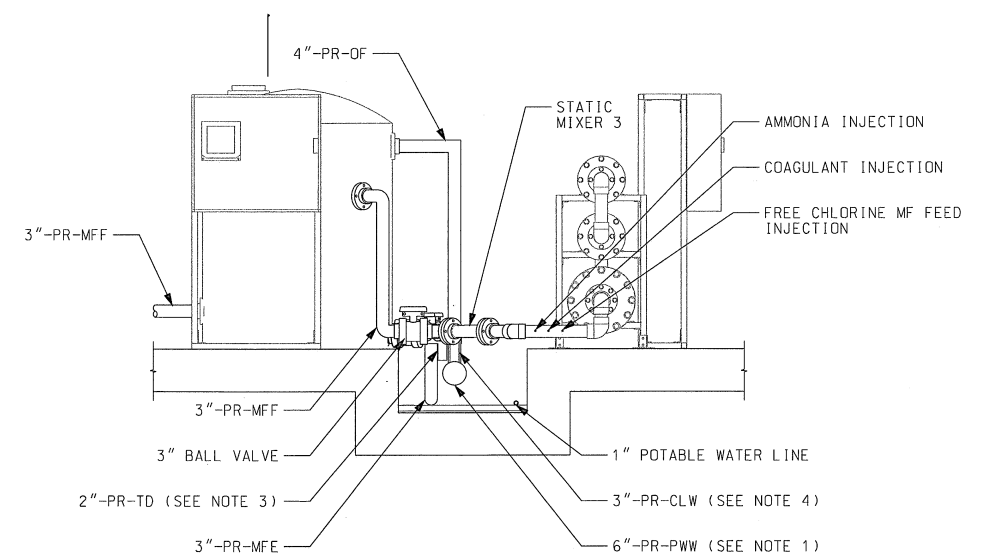
SOUTH TRENCH SECTION (WEST)
SCALE: 1/2" = 1'-0"

D
M-2



RO PERMEATE AND UV/AOP PIPING
SCALE: 1/2" = 1'-0"

E
M-2



NORTH TRENCH SECTION (EAST)
SCALE: 1/2" = 1'-0"

F
M-2

NOTES:

- 6"-PR-PWW SHALL HAVE 1% SLOPE TO ALLOW PROPER DRAINAGE.
- MINIMUM 0.5" CLEARANCE BETWEEN UNISTRUT AND TRENCH CONCRETE FLOOR.
- 500 GALLON PROCESS TANK DRAINS MAY BE PIPED TO DRAIN DIRECTLY INTO THE TRENCH.
- CHLORINE CONTACTOR EFFLUENT SHALL HAVE A CONNECTION TO THE 6"-PR-PWW AFTER STATIC MIXER 3 AND PRIOR TO MF FEED TANK.
- 3"-PR-INF SHALL CONNECT TO 4" AWP FEED LINE.
- 3"-PR-EFF SHALL CONNECT TO 4" AWP PRODUCT LINE.
- 6"-PR-PWW SHALL CONNECT TO 8" SEWER SERVICE LINE.

M-1

PADRE DAM MUNICIPAL WATER DISTRICT

AWP DEMONSTRATION FACILITY PIPING SECTIONS AND DETAILS

WESTERN SERVICE AREA	42884	SHEET OF	DRAWING NO
SCALE: AS SHOWN	JOB NUMBER	16 34	8018-ST



Trussell
TECHNOLOGIES INC

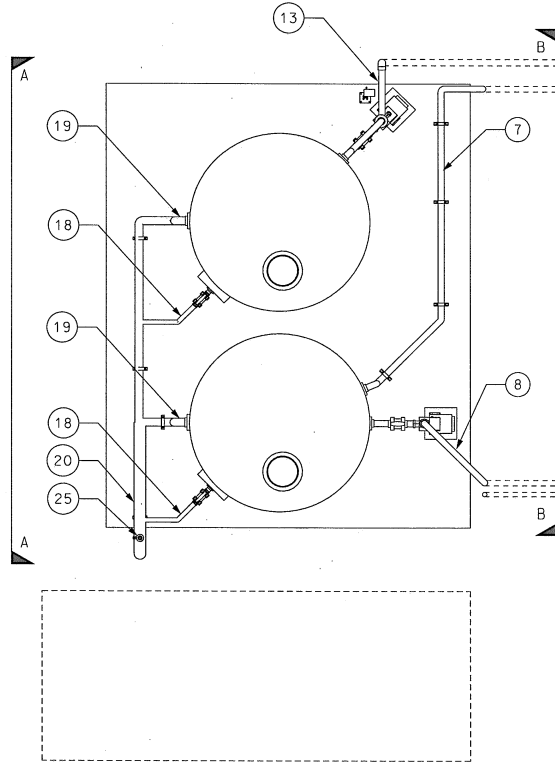
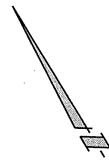
DRAWING REFERENCES:

SIGNATURE OF THESE PLANS IS NOT A COMMITMENT TO SERVE		
REV	DATE	DESCRIPTION

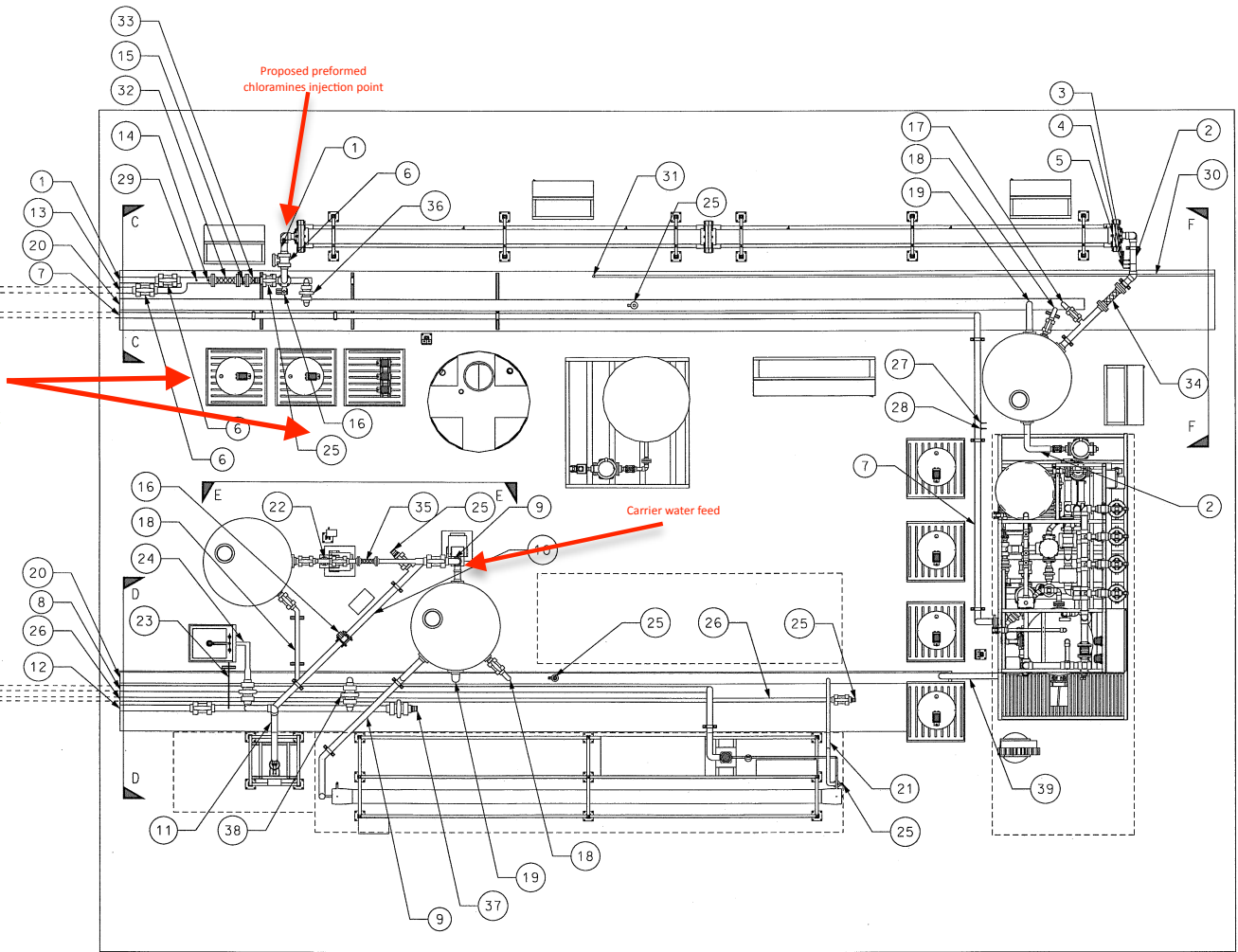
DESIGN BY:	RST/BMP	DRAWN BY:	EYI
RECOMMENDED BY:	ARNE S.	CHECKED BY:	RST/BMP

NOTES:

- ① 3"-PR-INF
- ② 3"-PR-MFF
- ③ FREE CHLORINE MF FEED INJECTION
- ④ COAGULANT INJECTION
- ⑤ AMMONIA INJECTION
- ⑥ BALL VALVE
- ⑦ 3"-PR-MFE
- ⑧ 3"-PR-ROF
- ⑨ 3"-PR-ROP
- ⑩ 3"-PR-UVF
- ⑪ 3"-PR-UVE
- ⑫ 3"-PR-EFF
- ⑬ 3"-PR-CHLG
- ⑭ MS2 INJECTION
- ⑮ NaOCl INJECTION
- ⑯ MAGNETIC FLOW METER
- ⑰ 3"-PR-CLW
- ⑱ 2"-PR-TD
- ⑲ 4"-PR-DF
- ⑳ 6"-PR-PWW
- ㉑ 2"-PR-ROC
- ㉒ 2"-PR-AOP
- ㉓ 1/2"-PR-SKF
- ㉔ 1-1/2"-PR-SKD
- ㉕ QUICK DISCONNECT
- ㉖ 2"-PR-ROC
- ㉗ AMMONIA INJECTION
- ㉘ TOTAL CHLORINE ANALYZER FEED
- ㉙ AMMONIA ANALYZER FEED
- ㉚ 1" POTABLE WATER SERVICE
- ㉛ POTABLE WATER HOSE BIB (WITH BACKFLOW PREVENTER)
- ㉜ STATIC MIXER 1
- ㉝ STATIC MIXER 2
- ㉞ STATIC MIXER 3
- ㉟ STATIC MIXER 4
- ㊱ 3" VALVED CONNECTION BETWEEN 3"-PR-INF AND 6"-PR-PWW TO ALLOW DRAINING OF AWP FEED LINE
- ㊲ 3" PIPING AND QUICK DISCONNECT TO ALLOW DRAINING OF AWP PRODUCT LINE
- ㊳ 3" VALVED CONNECTION BETWEEN 3"-PR-EFF AND 6"-PR-PWW TO ALLOW DRAINING OF AWP PRODUCT LINE
- ㊴ MF SYSTEM WASTE FLOWS TO 6"-PR-PWW



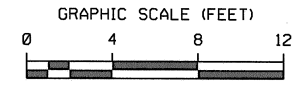
Proposed location for NaOH day tank



PLAN VIEW
SCALE: 1/4" = 1'-0"

GENERAL NOTES:

1. CONTRACTOR SHALL INSTALL PIPING, EQUIPMENT, INSTRUMENTATION AND CONTROLS IN A PROCESS ORDER CONSISTENT WITH THE PROCESS AND INSTRUMENTATION DIAGRAMS OF THIS DRAWING SET. NOT ALL INSTRUMENTATION, CHEMICAL INJECTION, AND SAMPLE PORT LOCATIONS HAVE BEEN CALLED OUT ON THIS SHEET TO MAINTAIN CLARITY.
2. GRATING OVER CONCRETE TRENCHES NOT SHOWN FOR CLARITY. GRATE SHALL BE CUT FOR PIPING GOING INTO AND OUT OF THE TRENCHES. CERTAIN CONNECTIONS MAY REQUIRE THE GRATING TO BE CUT TO ALLOW VERTICAL SPACE (E.G. ITEMS 36 AND 38). GRATING SHALL BE UN CUT TO ALLOW THE PERIMETER WALKWAY TO BE FREE OF TRIP HAZARDS.



M-2



Trussell
TECHNOLOGIES INC

DRAWING REFERENCES:

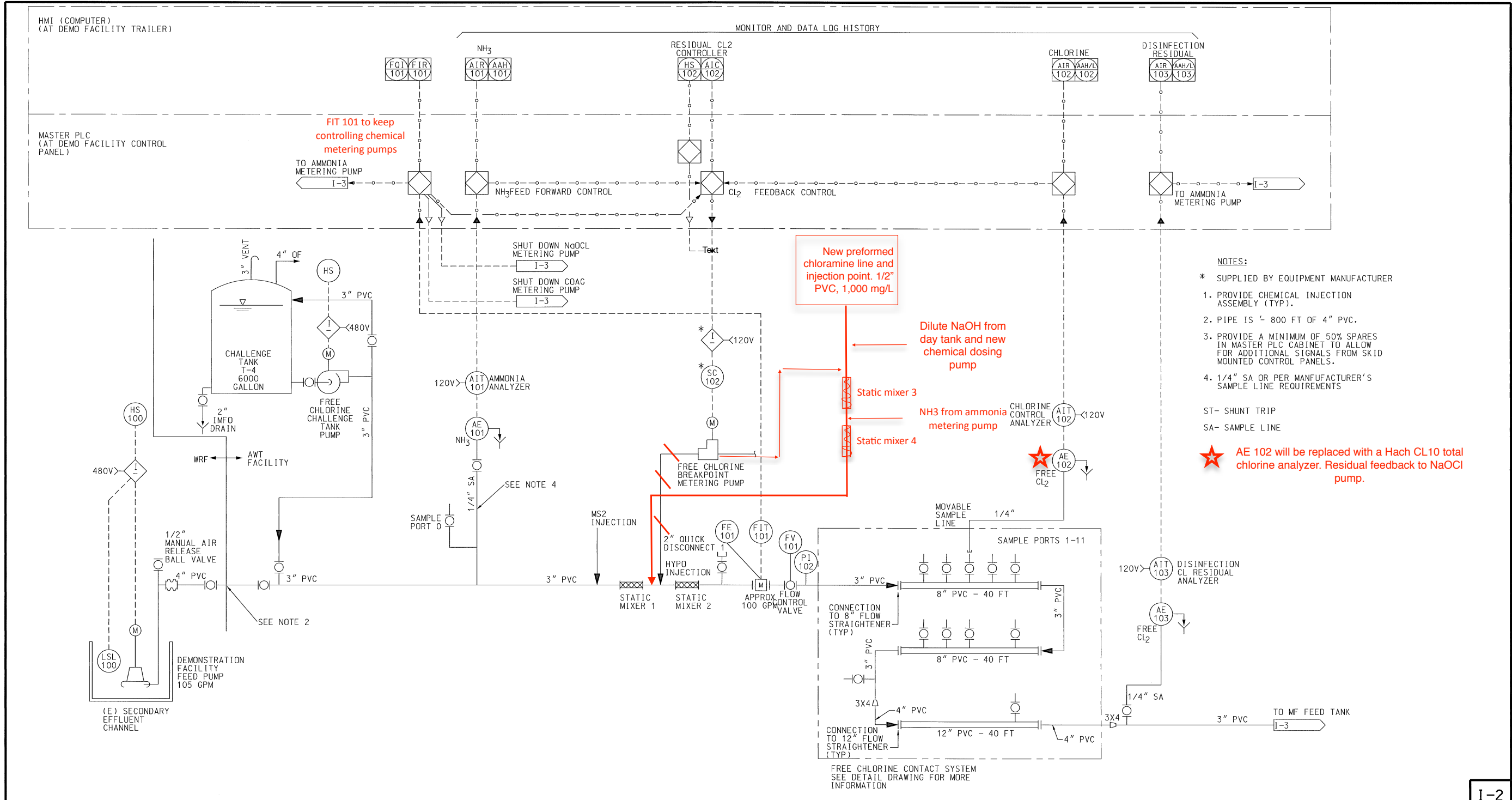
SIGNATURE OF THESE PLANS IS NOT A COMMITMENT TO SERVE		
REV	DATE	DESCRIPTION

DESIGN BY: RST/BMP	DRAWN BY: EYI
RECOMMENDED BY: ARNE S.	CHECKED BY: RST/BMP

PADRE DAM
MUNICIPAL WATER DISTRICT

AWP DEMONSTRATION FACILITY
PIPING PLAN AND SCHEDULE

WESTERN SERVICE AREA	42884 JOB NUMBER	SHEET OF 17 34	DRAWING NO 8019-ST
SCALE: AS SHOWN			



- NOTES:**
- * SUPPLIED BY EQUIPMENT MANUFACTURER
 - 1. PROVIDE CHEMICAL INJECTION ASSEMBLY (TYP).
 - 2. PIPE IS 800 FT OF 4" PVC.
 - 3. PROVIDE A MINIMUM OF 50% SPARES IN MASTER PLC CABINET TO ALLOW FOR ADDITIONAL SIGNALS FROM SKID MOUNTED CONTROL PANELS.
 - 4. 1/4" SA OR PER MANUFACTURER'S SAMPLE LINE REQUIREMENTS
- ST- SHUNT TRIP
SA- SAMPLE LINE
- ★ AE 102 will be replaced with a Hach CL10 total chlorine analyzer. Residual feedback to NaOCl pump.

I-2

PADRE DAM MUNICIPAL WATER DISTRICT

AWP DEMONSTRATION FACILITY PROCESS AND INSTRUMENTATION DIAGRAM CHLORINE DISINFECTION SYSTEM



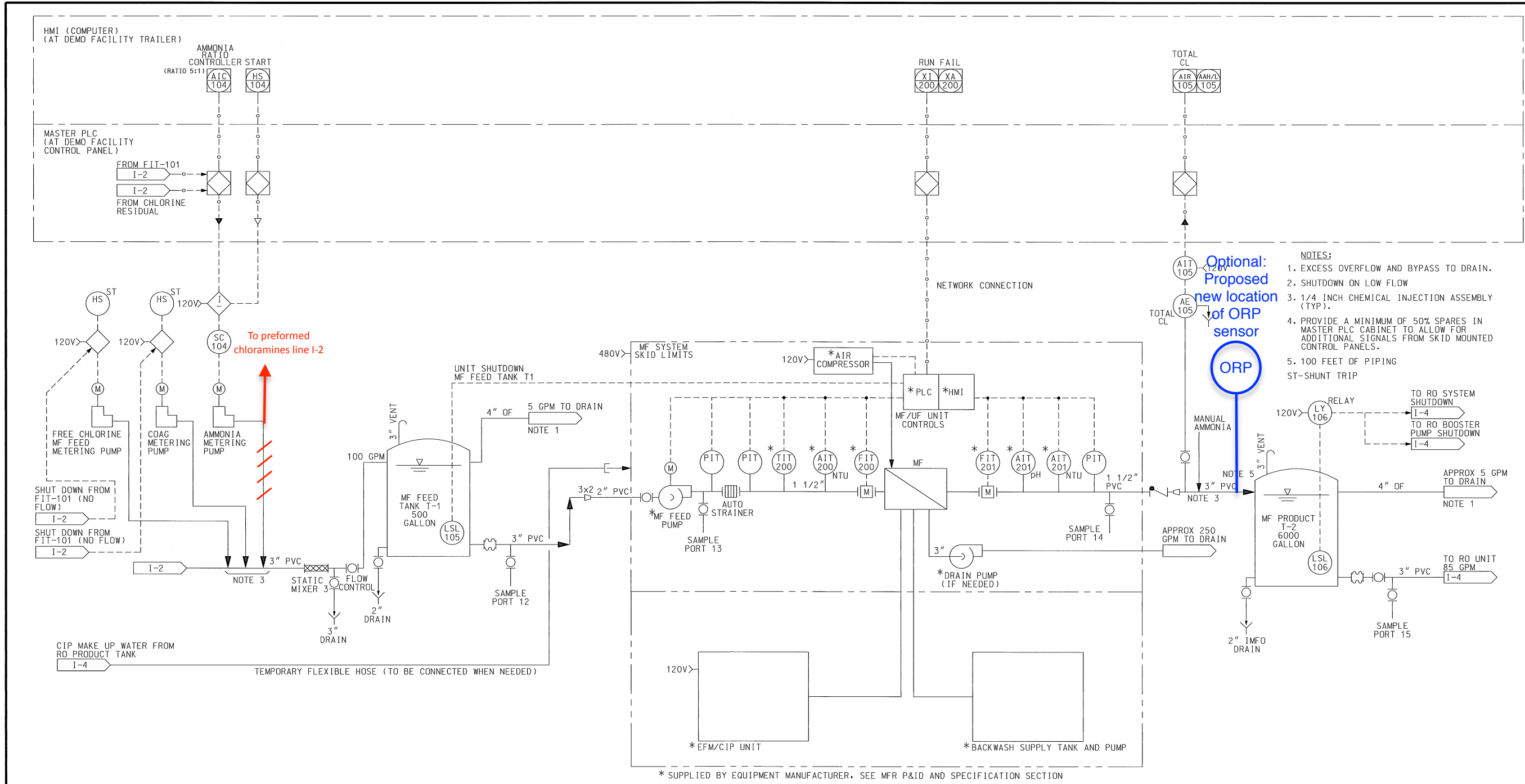
Kennedy/Jenks Consultants
Engineers & Scientists

ALL BEARINGS, DISTANCES AND COORDINATES ARE BASED ON PDMD DIGITAL MAP AND DISTRICT GPS CONTROL SURVEYS ROS 11252 AND 13702

SIGNATURE OF THESE PLANS IS NOT A COMMITMENT TO SERVE		
REV	DATE	DESCRIPTION

DESIGN BY:	TKR	DRAWN BY:	WL
RECOMMENDED BY:	ARNE S.	CHECKED BY:	KA/SD

WESTERN SERVICE AREA	42884	SHEET OF	30 34	DRAWING NO	8032-ST
SCALE:	NONE				



- NOTES:
1. EXCESS OVERFLOW AND BYPASS TO DRAIN.
 2. SHUTDOWN ON LOW FLOW
 3. 1/4 INCH CHEMICAL INJECTION ASSEMBLY (TYP).
 4. PROVIDE A MINIMUM OF 50% SPARES IN MASTER PLC CABINET TO ALLOW FOR ADDITIONAL SIGNALS FROM SKID MOUNTED CONTROL PANELS.
 5. 100 FEET OF PIPING ST-SHUNT TRIP

I-3

PADRE DAM MUNICIPAL WATER DISTRICT

AWP DEMONSTRATION FACILITY PROCESS AND INSTRUMENTATION DIAGRAM MF SYSTEM



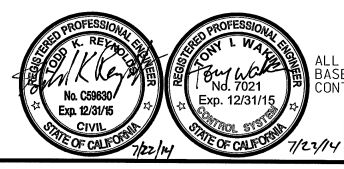
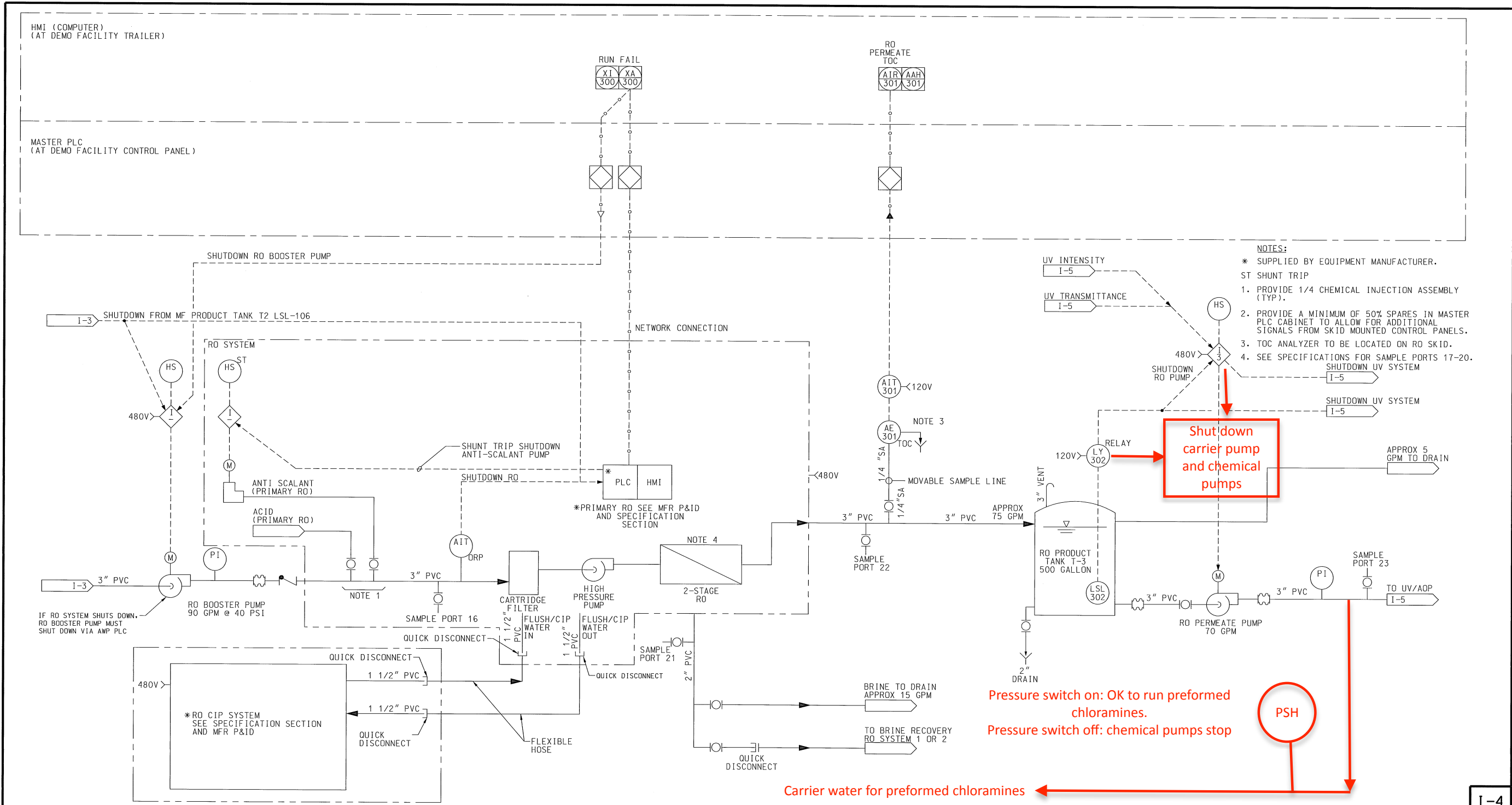
Kennedy/Jenks Consultants
Engineers & Scientists

ALL BEARINGS, DISTANCES AND COORDINATES ARE BASED ON PDMD DIGITAL MAP AND DISTRICT GPS CONTROL SURVEYS ROS 11252 AND 13702

SIGNATURE OF THESE PLANS IS NOT A COMMITMENT TO SERVE		
REV	DATE	DESCRIPTION

DESIGN BY: TKR	DRAWN BY: WL
RECOMMENDED BY: ARNE S.	CHECKED BY: KA/SD

WESTERN SERVICE AREA	42884 JOB NUMBER	SHEET OF 31 34	DRAWING NO 8033-ST
SCALE: NONE			



Kennedy/Jenks Consultants
 Engineers & Scientists

ALL BEARINGS, DISTANCES AND COORDINATES ARE BASED ON PDMD DIGITAL MAP AND DISTRICT GPS CONTROL SURVEYS ROS 11252 AND 13702

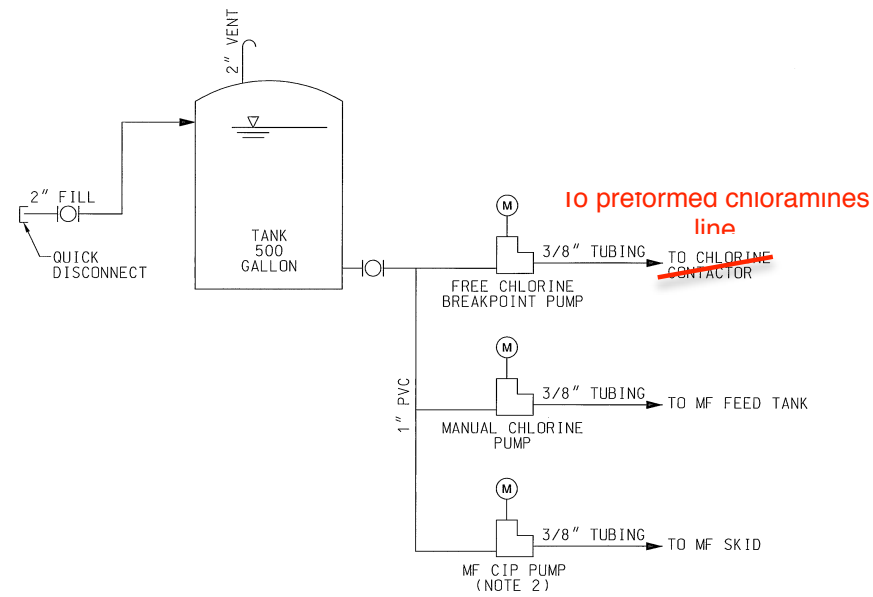
SIGNATURE OF THESE PLANS IS NOT A COMMITMENT TO SERVE		
REV	DATE	DESCRIPTION

DESIGN BY: TKR DRAWN BY: WL
 RECOMMENDED BY: ARNE S. CHECKED BY: KA/SD

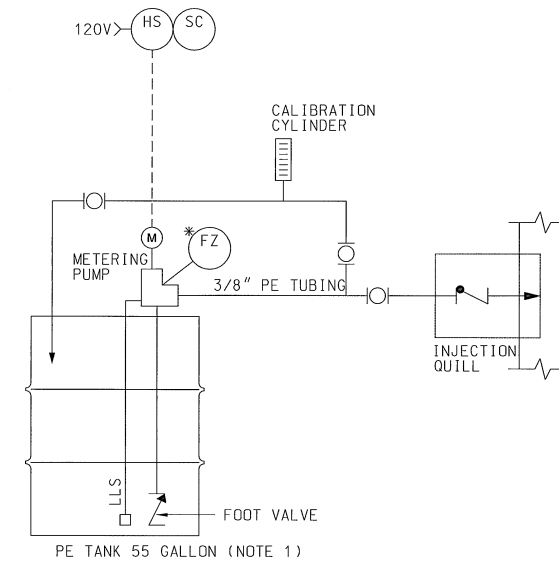
PADRE DAM MUNICIPAL WATER DISTRICT

AWP DEMONSTRATION FACILITY PROCESS AND INSTRUMENTATION DIAGRAM RO SYSTEM

WESTERN SERVICE AREA	42884 JOB NUMBER	SHEET 32 OF 34	DRAWING NO 8034-ST
SCALE: NONE			



HYPOCHLORITE CHEMICAL
FEED SYSTEM



TYPICAL CHEMICAL FEED SYSTEM

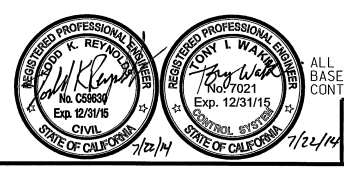
AMMONIA
FERRIC CHLORIDE
CAUSTIC (NOTE 2)
SULFURIC ACID (NOTE 3)
ANTISCALANT (NOTE 3)
CITRIC ACID (NOTE 2)

NOTES:

- OWNER TO SUPPLY CHEMICALS AND 55-GALLON CHEMICAL DRUMS.
- CHEMICAL FEED SYSTEM, EXCLUDING CHEMICAL AND CHEMICAL STORAGE, TO BE SUPPLIED BY MF SYSTEM SUPPLIER.
- CHEMICAL FEED SYSTEM, EXCLUDING CHEMICAL AND CHEMICAL STORAGE, TO BE SUPPLIED BY RO EQUIPMENT MANUFACTURER.

**PADRE DAM
MUNICIPAL WATER DISTRICT**

**AWP DEMONSTRATION FACILITY
PROCESS AND INSTRUMENTATION
DIAGRAM TYPICAL CHEMICAL
FEED SYSTEM**



**Kennedy/Jenks Consultants
Engineers & Scientists**

ALL BEARINGS, DISTANCES AND COORDINATES ARE BASED ON PDMWD DIGITAL MAP AND DISTRICT GPS CONTROL SURVEYS ROS 11252 AND 13702

DRAWING REFERENCES:

SIGNATURE OF THESE PLANS IS NOT A COMMITMENT TO SERVE		
REV DATE	DESCRIPTION	BY APPD

DESIGN BY: TKR DRAWN BY: WL
RECOMMENDED BY: ARNE S. CHECKED BY: KA/SD

WESTERN SERVICE AREA	42884	SHEET OF	34 34	DRAWING NO	8036-ST
SCALE:	NONE				

Appendix 2 - Data

Constituent	MRL	Units	Method	Eurofins report number																														
				816750	818052	819164	820490	821957	823296	824577	825622	826989	828497	829791	830777	832037	833485	834816	836231	837559	838849	840224	841227	842608	844114	845439	881972	883282	884433					
				Sampling Date																														
				7/18/19	7/25/19	8/1/19	8/8/19	8/15/19	8/22/19	8/29/19	9/5/19	9/12/19	9/19/19	9/26/16	10/2/19	10/9/19	10/16/19	10/23/19	10/31/19	11/7/19	11/14/19	11/21/19	11/26/19	12/5/19	12/12/19	12/19/19	7/16/20	7/23/20	7/30/20					
AWP Feed (before chloramination)																																		
Bromodichloromethane (BDCM)	0.50	µg/L	EPA 524.2	<0.5	NS	<0.5	NS	NS	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	<0.5	NS	NS	NS	NS	<0.5	NS	NS	<0.5	NS	NS	<0.5	NS	NS			
Dibromochloromethane (DBCM)	0.50	µg/L	EPA 524.2	<0.5	NS	<0.5	NS	NS	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	<0.5	NS	NS	NS	NS	<0.5	NS	NS	<0.5	NS	NS	<0.5	NS	NS			
Bromoform	0.50	µg/L	EPA 524.2	<0.5	NS	<0.5	NS	NS	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	<0.5	NS	NS	NS	NS	<0.5	NS	NS	<0.5	NS	NS	<0.5	NS	NS			
Chloroform (Trichloromethane)	0.50	µg/L	EPA 524.2	<0.5	NS	<0.5	NS	NS	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	<0.5	NS	NS	NS	NS	<0.5	NS	NS	<0.5	NS	NS	<0.5	NS	NS			
Total THM	0.50	µg/L	EPA 524.2	<0.5	NS	<0.5	NS	NS	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	<0.5	NS	NS	NS	NS	<0.5	NS	NS	<0.5	NS	NS	<0.5	NS	NS			
N-Nitroso-dimethylamine (NDMA)	2.0	ng/L	EPA 521	17	NS	8.8	NS	NS	NS	NS	NS	7.3	NS	NS	NS	5.5	NS	NS	NS	14	NS	NS	NS	3.4	NS	NS	10	NS	NS	NS	NS			
Bromide	5.0	µg/L	EPA 300.0	270	NS	280	NS	NS	NS	NS	NS	300	NS	NS	NS	280	NS	NS	NS	270	NS	NS	NS	260	NS	NS	250	NS	NS	NS	NS			
RO Feed																																		
Bromodichloromethane (BDCM)	0.50	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5		
Dibromochloromethane (DBCM)	0.50	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Bromoform	0.50	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Chloroform (Trichloromethane)	0.50	µg/L	EPA 524.2	1.1	0.62	0.64	0.81	0.7	<0.5	<0.5	<0.5	0.95	0.7	<0.5	1.8	<0.5	0.5	21	<0.5	<0.5	<0.5	0.56	<0.5	<0.5	0.54	<0.5	<0.5	0.55	<0.5	1.1	1.1	1.1		
Total THM	0.50	µg/L	EPA 524.2	1.1	0.62	0.64	0.81	0.7	<0.5	<0.5	<0.5	0.95	0.7	<0.5	1.8	<0.5	0.5	21	<0.5	<0.5	<0.5	0.56	<0.5	<0.5	0.54	<0.5	<0.5	0.55	<0.5	1.1	1.1	1.1		
N-Nitroso-dimethylamine (NDMA)	2.0	ng/L	EPA 521	20	NS	9.6	NS	9	NS	44	NS	8	NS	8.6	NS	5.4	NS	4.7	NS	13	NS	9.8	NS	4.6	NS	5.1	9.6	NS	12	12	12	12		
Di(2-Ethylhexyl)phthalate (DEHP)	0.60	µg/L	EPA 525.2	<0.6	NS	<0.6	NS	NS	NS	NS	NS	0.80	NS	NS	NS	<0.6	NS	NS	NS	<0.6	NS	NS	NS	<0.6	NS	NS	<0.6	NS	NS	NS	NS	NS		
RO Permeate																																		
Bromodichloromethane (BDCM)	0.50	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Dibromochloromethane (DBCM)	0.50	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Bromoform	0.50	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chloroform (Trichloromethane)	0.50	µg/L	EPA 524.2	0.66	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	3.6	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.7
Total THM	0.50	µg/L	EPA 524.2	0.66	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	3.6	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.7
N-Nitroso-dimethylamine (NDMA)	2.0	ng/L	EPA 521	15	6.5	7	5.9	5.6	4.8	31	6.4	4.9	6.1	4.6	5.3	3.8	4.1	3.2	2.2	9.4	4.7	6.2	2.5	2.4	2.3	2.7	6.3	7.4	8.3	8.3	8.3	8.3	8.3	
Di(2-Ethylhexyl)phthalate (DEHP)	0.60	µg/L	EPA 525.2	<0.6	NS	<0.6	NS	NS	NS	NS	NS	0.66	NS	NS	NS	<0.6	NS	NS	NS	<0.6	NS	NS	NS	<0.6	NS	NS	<0.6	NS	NS	NS	NS	NS	NS	
UV/AOP effluent																																		
Bromodichloromethane (BDCM)	0.50	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Dibromochloromethane (DBCM)	0.50	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Bromoform	0.50	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chloroform (Trichloromethane)	0.50	µg/L	EPA 524.2	1.1	1	<0.5	<0.5	1	<0.5	<0.5	1.4	0.67	<0.5	<0.5	<0.5	<0.5	<0.5	2.6	0.52	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.65
Total THM	0.50	µg/L	EPA 524.2	1.1	1	<0.5	<0.5	1	<0.5	<0.5	1.4	0.67	<0.5	<0.5	<0.5	<0.5	<0.5	2.6	0.52	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.65
N-Nitroso-dimethylamine (NDMA)	2.0	ng/L	EPA 521	<2	NS	<2	NS	<2	NS	<2	NS	<2	NS	<2	NS	<2	NS	<2	NS	<2	NS	<2	NS	<2	NS	<2	NS	<2	NS	<2	NS	<2	<2	
Di(2-Ethylhexyl)phthalate (DEHP)	0.60	µg/L	EPA 525.2	<0.6	NS	<0.6	NS	NS	NS	NS	NS	<0.6	NS	NS	NS	<0.6	NS	NS	NS	<0.6	NS	NS	NS	<0.6	NS	NS	<0.6	NS	NS	NS	NS	NS	NS	
Additional AWP Feed water testing																																		
Nitrate as Nitrogen by IC	0.1	mg/L	EPA 300.0	8.7																														
Alkalinity in CaCO3 units	2.0	mg/L	SM 2320B	100																														
Ammonia Nitrogen	0.05	mg/L	EPA 350.1	0.058																														
Total Dissolved Solids (TDS)	10	mg/L	E160.1/SM2540C	580																														
Total Organic Carbon	0.3	mg/L	SM 5310C	8.8																														

NS= NOT SAMPLED

Constituent	MRL	Units	Method	Eurofins report number																															
				885686	886413	887137	889124	889775	890925	891333	893347	894576	894577	895766	896481	897208	899269	899812	900921	901484	902216	903365	904666	905376	906173	906624	907550	908011	908695	908696					
				Sampling Date																															
				8/6/20	8/11/20	8/13/20	8/25/20	8/27/20	9/3/20	9/8/20	9/17/20	9/22/20	9/24/20	10/1/20	10/6/20	10/8/20	10/20/20	10/22/20	10/29/20	11/3/20	11/5/20	11/12/20	11/19/20	11/24/20	12/1/20	12/3/20	12/8/20	12/10/20	12/15/20						
AWP Feed (before chloramination)																																			
Bromodichloromethane (BDCM)	0.5	µg/L	EPA 524.2	NS	<0.5	NS	NS	NS	<0.5	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	NS	<0.5	NS	NS						
Dibromochloromethane (DBCM)	0.5	µg/L	EPA 524.2	NS	<0.5	NS	NS	NS	<0.5	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	NS	<0.5	NS	NS						
Bromoform	0.5	µg/L	EPA 524.2	NS	<0.5	NS	NS	NS	<0.5	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	NS	<0.5	NS	NS						
Chloroform (Trichloromethane)	0.5	µg/L	EPA 524.2	NS	<0.5	NS	NS	NS	<0.5	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	NS	<0.5	NS	NS						
Total THM	0.5	µg/L	EPA 524.2	NS	<0.5	NS	NS	NS	<0.5	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	NS	NS	NS	<0.5	NS	NS	NS	NS	<0.5	NS	NS						
N-Nitroso-dimethylamine (NDMA)	2.0	ng/L	EPA 521	NS	9.2	NS	NS	NS	8.9	NS	NS	NS	NS	NS	6.8	NS	NS	NS	NS	NS	NS	3.8	NS	NS	NS	NS	3.9	NS	NS						
Bromide	5.0	µg/L	EPA 300.0	NS	250	NS	NS	NS	220	NS	NS	NS	NS	NS	220	NS	NS	NS	NS	NS	NS	220	NS	NS	NS	NS	190	NS	NS						
RO Feed																																			
Bromodichloromethane (BDCM)	0.5	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5						
Dibromochloromethane (DBCM)	0.5	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5						
Bromoform	0.5	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5						
Chloroform (Trichloromethane)	0.5	µg/L	EPA 524.2	<0.5	0.95	<0.5	<0.5	<0.5	<0.5	0.85	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.97	0.58	<0.5	<0.5	<0.5	0.64	0.51	0.53	0.54	0.51	<0.5	<0.5	0.52						
Total THM	0.5	µg/L	EPA 524.2	<0.5	0.95	<0.5	<0.5	<0.5	<0.5	0.85	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.97	0.58	<0.5	<0.5	<0.5	0.64	0.51	0.53	0.54	0.51	<0.5	<0.5	0.52						
N-Nitroso-dimethylamine (NDMA)	2.0	ng/L	EPA 521	NS	9.4	NS	17	15	10	NS	NS	9.7	NS	6.7	6.1	NS	NS	NS	9.4	5	NS	3.8	NS	5.8	4.9	NS	4	6	8.7						
Di(2-Ethylhexyl)phthalate (DEHP)	0.6	µg/L	EPA 525.2	NS	<0.6	NS	NS	NS	<0.6	NS	NS	NS	NS	NS	<0.6	NS	NS	NS	NS	NS	<0.6	NS	NS	NS	NS	<0.6	NS	NS							
RO Permeate																																			
Bromodichloromethane (BDCM)	0.5	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5						
Dibromochloromethane (DBCM)	0.5	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5						
Bromoform	0.5	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5						
Chloroform (Trichloromethane)	0.5	µg/L	EPA 524.2	<0.5	0.55	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.56	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5							
Total THM	0.5	µg/L	EPA 524.2	<0.5	0.55	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.56	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5							
N-Nitroso-dimethylamine (NDMA)	2.0	ng/L	EPA 521	14	7.5	8.7	12	10	6.6	7.5	5.1	7.4	4.7	4.3	5	5.6	5.6	4.6	6.5	3.2	3	2.3	5.6	3.2	2.9	3.1	2.3	3.6	5.2						
Di(2-Ethylhexyl)phthalate (DEHP)	0.6	µg/L	EPA 525.2	NS	<0.6	NS	NS	NS	<0.6	NS	NS	NS	NS	NS	<0.6	NS	NS	NS	NS	NS	<0.6	NS	NS	NS	NS	<0.6	NS	NS							
UV/AOP effluent																																			
Bromodichloromethane (BDCM)	0.5	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5						
Dibromochloromethane (DBCM)	0.5	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5						
Bromoform	0.5	µg/L	EPA 524.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5						
Chloroform (Trichloromethane)	0.5	µg/L	EPA 524.2	<0.5	<0.5	<0.5	0.71	0.87	<0.5	0.82	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.59	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5						
Total THM	0.5	µg/L	EPA 524.2	<0.5	<0.5	<0.5	0.71	0.87	<0.5	0.82	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.59	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5						
N-Nitroso-dimethylamine (NDMA)	2.0	ng/L	EPA 521	NS	<2	NS	<2	<2	<2	NS	NS	<2	NS	<2	<2	NS	NS	NS	<2	<2	NS	<2	NS	<2	<2	NS	<2	<2	<2						
Di(2-Ethylhexyl)phthalate (DEHP)	0.6	µg/L	EPA 525.2	NS	<0.6	NS	NS	NS	<0.6	NS	NS	NS	NS	NS	<0.6	NS	NS	NS	NS	NS	<0.6	NS	NS	NS	NS	<0.6	NS	NS							